

Airway Management with Endotracheal Tube versus Combitube[®] during Parabolic Flights

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Background: Training of National Aeronautics and Space Administration space shuttle astronauts revealed difficult airway management with endotracheal tubes (ETTs) under microgravity conditions. The authors performed a randomized comparative study of ETT and Combitube[®] (ETC; Tyco Healthcare, Pleasanton, CA). The aim of the study was to evaluate ease, time of insertion, and success rates during normogravity and parabolic flights using mannequins.

Methods: After normogravity experiments, four flyers performed intubation on a mannequin during the flights. Sixty-two intubation attempts were performed using the ETC (normogravity, 29; microgravity, 33), and 58 intubation attempts were performed using the ETT (each 29 attempts, both conditions). Time to completion of the intubation procedure, success rate, and ease of insertion were recorded.

Results: The ETC performed equally well between normogravity (median, 18 s; range, 17–25 s) and microgravity (median, 18.5 s; range, 17–28 s), whereas the ETT performed significantly slower under microgravity (median, 20 s; range, 17–27 s) as compared with normogravity (median, 18 s; range, 16–22 s; $P = 0.019$). One hundred nine of 120 (90%) were successful. The ETT and ETC were comparable with respect to successful intubations, under normogravity or microgravity, respectively.

Conclusions: Both the ETC and ETT perform comparably well. Slight differences could be found with respect to time of insertion in favor of the ETC. Because this is the first experiment using the ETC on the KC-135, it is shown that there is enough time to perform the insertion procedure. Because the ETC airway requires less training and is easier to insert than an ETT, it is recommended for further study as an alternative airway to what is currently on the shuttle.

THE United States began its space journey with the Gemini, Mercury, and Apollo programs. It was those programs that led to today's shuttle missions. Now, the focus is on long-duration missions on the Interna-

tional Space Station and voyaging to Mars. With prospects such as these, it is apparent that airway emergencies may occur during prolonged spaceflights. During these flights, there may be an increased risk of hypoxic cardiopulmonary arrest, aspiration of foreign bodies, and burns.¹ It is known that if an airway emergency were to take place on such a mission, medical evacuation is not a suitable option because of distance and the need of the human brain to receive oxygen immediately to avoid brain tissue death. It is therefore imperative that immediate care be given while onboard the orbiter/station.

Currently, the space shuttle carries endotracheal tubes (ETTs), and there is also a tracheostomy kit that can be used to perform a surgical incision into the trachea for the placement of a tracheostomy.¹ Under the special circumstances of weightlessness during spaceflights, both of these procedures may be extremely difficult, invasive, and risky and require lengthy training and experience. The best approach to these studies is through formal investigations during spaceflight.² A limited number of such studies have been performed, but only one has emphasized airway management.² However, it is not known what is the best nonsurgical airway under conditions of microgravity—"best" being defined as a airway that requires minimal training to use, is easy to insert, and has a high degree of success. We chose the ETC, because the advantages of the ETC over other supraglottic alternate airway devices include its safety against aspiration,^{3,4} applicability of high ventilatory pressures,^{5,6} immediate fixation,⁷ ease of insertion,^{8,9} and slim design¹⁰ making it helpful also in patients with a small interincisor distance.

Therefore, we planned to perform the first comparative airway device study during parabolic flight aboard the National Aeronautics and Space Administration (NASA) KC-135. In this experiment, we compared the current standard ETT with an esophageal tracheal Combitube[®] (ETC; Tyco Healthcare, Nellcor Mallinckrodt, Pleasanton, CA). The latter device requires little effort to insert and no visualization with a laryngoscope, one size fits almost all patients, and it works successfully regardless of whether it is placed in the esophagus or the trachea.¹¹ To our knowledge, this airway has not been tested in microgravity and therefore requires consideration. We designed, built, and tested such a model on the ground and onboard the NASA KC-135A reduced-gravity aircraft.

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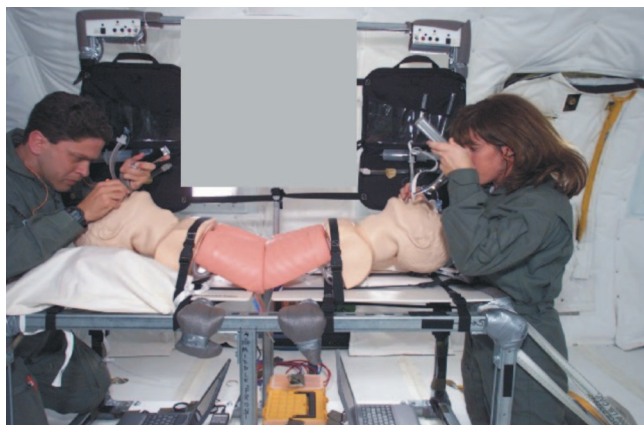


Fig. 1. Experimental apparatus showing the frame holding the two mannequins and the two flyers.

The purpose of this study was to compare the two airways during parabolic flight to determine whether one is more advantageous over the other during microgravity. We measured time of insertion and recorded the success rates of intubation.

Materials and Methods

The need for approval by institutional review board and NASA/Johnson Space Center Human Research Subject Consent Form was waived because there were no human, animal, or biologic experimental subjects in the experiment.

Study Design

The experiment involved the comparison of speed, accuracy, and subjective ease of insertion of the ETT *versus* the ETC. Four flyers participated in the experiment, two of them flying together during each flight. Each of the two flyers had an experimental station where they performed intubations on an airway mannequin simultaneously (fig. 1). The flight dates were March 29 and 30, 2001. The normogravity intubations were performed during the 2 days before the flight.

Each of two flyers had an experimental station where they performed an intubation on an airway mannequin simultaneously during the flights. Leg straps were used to maintain stabilization of the flyer, and the mannequin was firmly fixed to the experimental station, which in turn was firmly fixed to the flight craft. Intubation attempts began at the end of the pull-up phase when microgravity commenced. During the zero microgravity phase of the flight lasting up to 30 s, each flyer intubated the mannequin with one of the two airway devices. The order of intubations with each airway device was randomized. Each flyer performed one insertion per parabolic flight. Each procedure

started at the onset of microgravity, with the flyer initiating a computer-controlled device hooked to two laptops that indicated which airway device to use and then started a timer.

The tracheal intubation procedure involved a laryngoscope with a MacIntosh No. 3 blade to visualize the glottic opening to directly place the ETT (7.5 mm ID; Tyco Healthcare) through the vocal cords into the trachea. After placement, the cuff was then inflated with 10 ml of air from a blunt-tipped plastic syringe to secure the airway. At this point, the flyer stopped the timer, and the computer recorded the elapsed procedural time. Before success of each intubation attempt was determined, flyers rated the ease of intubation as 1 (very easy), 2 (easy), 3 (moderate), 4 (difficult), or 5 (very difficult).

Verification of successful airway placement was then determined by using a bag-valve device that inflated the lungs bilaterally and equally. At this point, the parabolic flight was finished, and the flyer then prepared the equipment for the next parabolic flight. All equipment was kept in equipment pouches attached to the frame.

The ETC (size 37F SA)†† was inserted directly into the oropharynx without direct visualization.^{11,12} After placement, the oropharyngeal balloon was inflated with 85 ml of air and the distal cuff was inflated with 10 ml of air with the help of blunt-tipped plastic syringes, which secured the airway. At this point, the flyer again stopped the timer, and the computer recorded the elapsed procedural time. Ease of intubation was evaluated as described above. Verification of successful airway placement was again determined using a bag-valve device and watching for equal rise and fall of the mannequin lungs.¹³ At the end of the parabolic flight, the flyer prepared the equipment for the next parabolic flight.

The data consisted of the elapsed time for intubation and whether the intubation was a success or not. Success was defined as rise and fall of the lungs of the mannequin with ventilation by the bag-valve device. After completion of the program, we analyzed the data and determined whether there was a statistically significant difference between the average intubation time and the success rate.

Paramedics Flyers

The four flyers were paramedics of the San Diego State University (San Diego, California) with more than 2 yr of experience as paramedic flyers. Each flyer had had considerable prestudy training and experience with endotracheal and ETC intubation, with approximately 75 successful intubations on mannequins with each method, three flyers with actual live intubations varying in number and one flyer without live intubation experience. The same experiment was performed on the ground as a control. The only difference was that during the parabolic flights, the flyers used Scop-Dex, an antiemetic medication provided before flight. Scop-Dex is a combi-

†† www.combitube.org. Accessed June 27, 2006.

nation of scopolamine (0.4 mg) and dextroamphetamine (5 mg), combined in a gel capsule, provided by NASA, yet not commercially available. It may have a beneficial effect in some people in preventing the vomit reflex.

Learning Curve during Parabolic Flight

Because one of the flyers performed only seven intubations (in each of the four possible permutations), time to completion of the intubation procedure was compared between attempts 1–7 to determine whether there was an effect of attempt number on time to intubation, *i.e.*, a learning effect. Success rates of intubation according to the number of intubation attempts were also compared.

Equipment Description and Structural Design

The equipment to be loaded onto the airplane consisted of a self-contained experimental apparatus diagrammed below (fig. 1). The major components of the system were as follows: The frame was made of commercially available Unistrut steel bars (ASTM A607 Steel, grade 50, hot rolled; Unistrut, Wayne, MI). Each frame component had a tensile yield strength of 15,000 lb. There were six bolts (1/2-inch SAE steel) securing the structure to the 20-inch square bolt grid on the aircraft floor. Each bolt had yield strength of 4,000 lb in shear.

To calculate maximum loads, we assumed the worst-case scenario of the center of mass of our experiment to be at the top of the structure. The maximum horizontal and vertical loads to be resisted were 9g and 7g, respectively (g used as unit for acceleration of gravity: $1g = 9.81 \text{ ms}^{-2}$). Hence, the maximum loading at any point of the apparatus would be 52° between these two directions, or $(9^2 + 7^2)^{1/2} g = 11.4g$. With the margin of safety significantly larger than one for both of the major structural components, we concluded that the design would keep its structural integrity on board the KC-135A aircraft.

Mannequins

The main working components of our experiment were the two airway mannequins placed horizontally on the framework (fig. 1). Each mannequin (Laerdal Airway Management Trainer; Wappingers Falls, NY) came securely attached to a composite-plastic backboard when purchased. Holes were drilled in the backboard and bolted the setup to our framework, using six bolts for each mannequin (one at each corner, and one in the middle of each long side). Mannequin dimensions were $20 \times 27 \times 10$ inches (W \times L \times H).

Intubation Components

The flyers used a set including an ETT, an ETC, a laryngoscope, three blunt-tip syringes, and a bag-valve device. The laryngoscope was used to insert the ETT into the mannequin. When inserted, the syringes were used

to inflate the various cuffs of the ETT. Last, the bag-valve device was attached to the end of the ETT, and air was forced into the mannequin (to check for successful intubation).

Each of these components was easily accessible to the flyer during the course of the experiment. To achieve this without relying on gravity to keep them on a horizontal surface, each component was attached with Velcro to the vertical backboard of the frame. Each component (except for the laryngoscope) was light enough so that it would not be dislodged during the high-g portions of the flight. The laryngoscope, however, was too heavy and instead was securely clipped to the backboard of the mannequin when not in use.

Data Acquisition System

There were two camcorders mounted on the framework, one above each flyer. Each camcorder was enclosed in a small "safety cage" to protect it from other passengers during microgravity.

Equipment Drawer

There was an enclosed equipment drawer bolted to the frame. All intubation components were placed in this drawer during takeoff and landing.

Electrical System

During flight, all electrical devices (two camcorders and a laptop computer) were operated using batteries. There was no electrical connection to the outside of the KC-135.

Hazard Analysis

There were no hazardous materials used in our experiment; also, there was no loose equipment. Under worst-case scenarios, a possible complication could be that one of our intubation components could free itself from the Velcro backboard. To address this possibility, all intubation components were tethered. In addition, all of the framing was padded to prevent any injury.

Statistical Analysis

Rates of successful intubations under normogravity and microgravity using either airway device (ETT or ETC) were analyzed using the Fisher exact test (exact significance, two-sided). The ease of intubation under different gravity conditions and using either airway device was analyzed using the Pearson chi-square test. We compared time to completion of the intubation procedure under normogravity and microgravity using either airway device (ETT or ETC) by use of the Mann-Whitney U test. Univariate analyses of variance were used to determine the influence of gravity (normogravity *vs.* microgravity) or airway device (ETT *vs.* ETC) on the time to completion of the intubation procedure. Learning curve: Times to completion of the intubation procedure

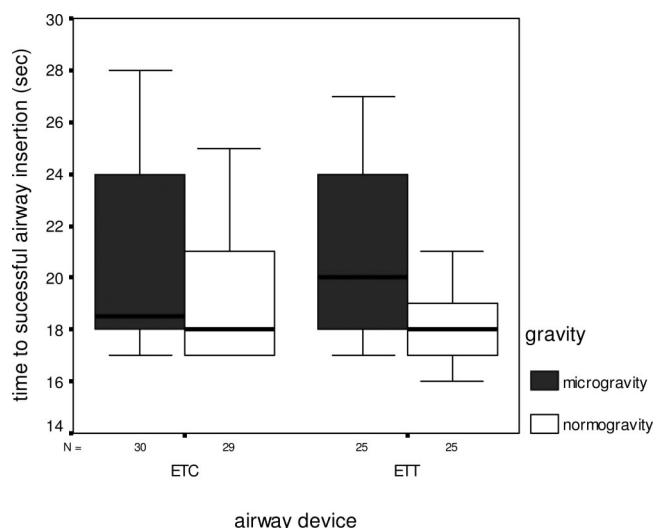


Fig. 2. Box-and-whisker plots showing times to successful intubation using the esophageal tracheal Combitube® (ETC) or the endotracheal tube (ETT) under normogravity and microgravity.

were compared using the Wilcoxon signed-rank test. Success rates of intubation according to the number of intubation attempts were compared using the Fisher exact test (exact significance, two-sided). SPSS statistical software system (version 10.0; SPSS Inc., Chicago, IL) was used for all calculations. A *P* value of less than 0.05 was considered to be significant.

Results

Time to Completion of the Intubation Procedure

In these series of experiments, a total of 120 intubation attempts were performed: 62 intubation attempts were performed using the ETC (normogravity, 29; microgravity, 33), and 58 intubation attempts (each 29 attempts under normogravity and microgravity, respectively) were performed using the ETT. The four flyers performed 16/18, 14/17, 14/17, and 14/10 normogravity/microgravity intubations, respectively.

The ETC performed equally well between normogravity (median, 18 s; range, 17–25 s) and microgravity (median, 18.5 s; range, 17–28 s) (*P* = not significant [NS]), whereas the ETT performed significantly poorer under microgravity (median, 20 s; range, 17–27 s) as compared with attempts performed under normogravity (median, 18 s; range, 16–22 s) (*P* = 0.019; fig. 2).

However, the time to completion of the intubation procedure between the ETC *versus* the ETT did not differ significantly under microgravity or normogravity conditions, respectively. Box-and-whisker plots showing times to successful intubation using the ETC or the ETT under normogravity and microgravity, respectively, are depicted in figure 2. Univariate analysis of variance revealed that neither gravity nor type of airway significantly influenced the time to completion of the intubation procedure.

Table 1. Ease of Insertion of the Two Airways under Normogravity and Microgravity

	Rated Ease of Airway Insertion,			
	Very Easy	Easy	Moderate	Difficult
Microgravity				
ETC	3	55	36	6
ETT	0	24	66	10
Normogravity				
ETC	28	66	7	0
ETT	21	52	28	0

ETC = esophageal tracheal Combitube®; ETT = endotracheal tube.

Ease of Intubation

Under normogravity, attempts using the ETC were rated as very easy in 8 cases (28%), easy in 19 (66%), and moderate in 2 (7%), whereas using the ETT attempts were rated as very easy in 6 (21%), easy in 15 (52%), and moderate in 8 (28%) (*P* = NS; table 1).

Under microgravity, intubation attempts using the ETC were rated as very easy in 1 case (3%), easy in 18 (55%), moderate in 12 (36%), and difficult in 2 (6%), whereas intubation attempts using the ETT under microgravity were rated as very easy in 0 cases, easy in 7 (24%), moderate in 19 (66%), and difficult in 3 (10%) (*P* = NS).

Success Rates of Intubation

One hundred nine (91%) of the 120 intubations were successful. Using the ETC, success rates were 100% (29 of 29 attempts) and 91% (30 of 33) under normogravity and microgravity, respectively (*P* = NS). Likewise, using the ETT, success rates were identical between normogravity and microgravity with 86% (25 of 29 attempts each) being successful (*P* = NS). Differences in success rates between the ETC and ETT were not significant under normogravity (*P* = NS) or microgravity (*P* = NS). Failure of intubation with the ETC was due to inability to place the ETC into the mannequin's esophagus because resistance was felt. Failure of intubation with the ETT was due to inability to visualize the vocal cords. All failures were rated as either moderate or difficult. Univariate analysis of variance revealed that neither gravity nor type of airway significantly influenced the time to completion of the intubation procedure.

Learning Curve during Parabolic Flight

Influence of the Number of Intubation Attempts on the Time to Intubation. Times to completion of a successful intubation procedure according to the number of intubation attempts using either airway device under either gravity condition are depicted in table 2.

The number of flyers (*n* = 4) was too small to allow for analyses in changes of time to intubation between attempt numbers in subgroups under different gravity conditions and/or using different airway devices.

Table 2. Time to Completion of Intubation Procedure According to Number of Attempts Using ETC or ETT under Normogravity and Microgravity

	Time to Successful Intubation, s						
	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5	Attempt 6	Attempt 7
ETC							
Normogravity	19 (18–25)	19 (17–23)	20 (17–22)	18 (17–21)	18 (17–22)	18 (18–21)	17 (17–21)
Microgravity	20 (17–32)	18 (17–28)	19 (18–26)	19 (17–28)	19 (18–27)	19 (18–26)	21 (17–25)
ETT							
Normogravity	22 (17–22)	19 (19–19)	19 (17–20)	18 (16–28)	19 (18–20)	17 (17–18)	18 (17–19)
Microgravity	22 (19–25)	20 (19–24)	21 (17–26)	21 (18–25)	19 (17–25)	18 (17–27)	19 (18–26)

ETC = esophageal tracheal Combitube®; ETT = endotracheal tube.

Influence of the Number of Intubation Attempts on the Success Rate of Intubation. Using the ETC, success rates of intubation attempts 1–7 were 7/8, 8/8, 6/8, 8/8, 8/8, 7/7, and 7/7 (all *P* values > 0.05). Similarly, using the ETT, success rates of intubation attempts 1–7 were 7/8, 6/8, 6/8, 7/8, 8/8, 6/7, and 6/7 (all *P* values > 0.05).

The number of flyers (*n* = 4) was too small to allow for analyses of success rates of intubation between attempt numbers in subgroups according to different gravity conditions and using different airway devices.

Discussion

The purpose of this study was to compare the performance of the ETC with the ETT during the microgravity phase of parabolic flight. We found that time for completion of the insertion procedure and success rates were in favor of the ETC; however, these statistical differences do not necessarily translate into clinical significance. Ease of insertion was comparable between the ETC and ETT for our experienced parabolic flyers. Nevertheless, the flyers remarked that much more skill and concentration was required to perform the ETT procedure as compared with the ETC procedure. The number of flyers was too small to allow for analysis of the success rate of intubation in relation to the number of attempts.

Although both the ETC and the laryngeal mask airway are widely used in the prehospital setting, we chose to compare the ETT to the ETC because the ETC is the first rescue option in many Emergency Medical Systems (*e.g.*, in San Diego, California), the ETC affords protection against aspiration, and the ETC has a relatively high leak pressure compared with the laryngeal mask airway. In addition, the flyers participating in the study were not trained in the use of the laryngeal mask airway before the onset of the study.

There are a number of theoretical/potential limitations to the study, and they consist of the existence of hypergravity before microgravity, the presence of motion sickness in two of the flyers, and the fact that the mannequin victim was not weightless. First, while hypergravity ex-

ists before microgravity during parabolic flight, thereby possibly affecting the results of this study, the intubation procedures started immediately after the achievement of microgravity. In addition, our experimental design eliminated differences in preparation between the ETT *versus* the ETC by making all of the equipment readily available. This might not be true in spaceflight (*e.g.*, insertion of the ETC does not require a laryngoscope), and the fixation requirements of the ETT are greater than for the ETC.

Second, two flyers claimed that their performance was hampered by medication and/or motion sickness, whereas the other pair of flyers did not experience these adverse effects. Two flyers who experienced motion sickness were unable to finish the entire experiment; if each flyer had successfully completed the experiment, there would have been an equal number of attempts for each tube. One flyer stated that the “newness” of microgravity was a distraction and may have played a role in some failures.

Third, the leg restraints were subjectively graded as “adequate” restraining devices for the insertion procedures in our experimental setup. However, a limitation in the design of this study is the mannequin was not weightless (*i.e.*, the mannequin is fixed to the experimental station, which in turn is fixed to the flight craft), whereas a space person would be floating. Because of potential damage to the airplane, NASA did not allow us to perform intubation in an unrestrained mannequin. The study is regarded as being an intermediate step toward figuring out what would be the best emergency airway during zero gravity. However, if a patient requires intubation in a shuttle, it may be advisable to first restrain the rescuer and/or the patient.

Recently published research indicates that anesthesiologists who are very competent at providing such airway care in normogravity had difficulties providing the same care and using similar airway adjuncts in simulated microgravity.¹ The free-floating condition in which the mannequin was not fixed increased the difficulty of ETT intubation compared with the restrained condition.¹ However, the ETT intubation was more difficult under

microgravity even with the mannequin restricted than under normal gravity. Such influences of microgravity seem to be minimal for insertion of the extratracheal airway devices. Notably, the investigator was not restrained in this experiment.¹ Although time to successful intubation was significantly longer with the ETT under microgravity as compared with normogravity in our experiment, this difference is clinically not relevant. However, in our study, both the mannequin and investigator were fixed because of the requirements of NASA. The unusual situation during parabolic flights may impair advanced motor skills, thereby making ETT intubation more difficult under microgravity. Our experiment suggests a potential advantage of ETC over ETT insertion because fixation of both the mannequin and the investigator did not eliminate difficulty in insertion of the ETT under microgravity.

Norfleet comments that these investigators¹ used water immersion as a model of microgravity, a reasonable choice because immersion facilities are readily available.¹⁴ 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).

Norfleet has evaluated laryngoscopic techniques during parabolic flight when the mannequin, as in this study, was fixed and immobile. He 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.¹⁴ This technique may be compared to what is called the “sit down-lean back technique” as used by paramedics in the field to stabilize the victim's head. A recent study determined the feasibility of laryngoscope-guided tracheal intubation in microgravity obtained during parabolic flight and tested the hypothesis that laryngoscope-guided tracheal intubation is similarly successful in the free-floating condition, with the patient's head gripped between the anesthesiologist's knees, as in the restrained condition, with the torso strapped to the surface.² Three personnel with no experience in airway management or microgravity participated in the study. There were no differences in ventilation success (41% *vs.* 33%) or time to successful insertion (both 18 s) between the free-floating and the restrained conditions. There were no differences in success rate between the free-floating condition, with the head gripped between the knees, and the restrained condition, with the torso strapped to the surface. The authors conclude that laryngoscope-guided tracheal intubation is feasible in microgravity obtained during parabolic flight, but the success rate is infrequent because of severe time restrictions.² Several studies

have shown that naive emergency medical technicians achieve a high level of success with the ETC in the prehospital setting.^{15–17} These results are especially surprising because most of the emergency medical technicians perform intubation once in a period of 18 months.^{15–17}

Conclusion

Data suggest that both airways can be inserted successfully during microgravity. Both the ETC and the ETT perform comparably well. Because this is the first experiment using the ETC on the KC-135, it is shown that there is enough time to perform the insertion procedure. Therefore, further testing on the KC-135 is reasonable. Because the ETC airway requires no surgical procedure and less training and is easier to insert than an ETT, it is recommended for further study as an alternative airway to what is currently on the shuttle. Another recommendation would be to use flyers with the same airway training as the astronauts and then make comparisons. It is also recommended that the flyers have experience on the KC-135 so that motion sickness, the distraction of “floating,” and aircraft operation do not affect the outcome of the experiment. The overall equipment setup seems to be optimal for flyer performance. The results of our study might aid in developing future protocols for managing airway emergencies on space missions.

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