BJA

British Journal of Anaesthesia, 125 (1): e47–e53 (2020)

doi: 10.1016/j.bja.2019.11.029
Advance Access Publication Date: 6 January 2020
Clinical Investigation

CLINICAL INVESTIGATION

Tracheal intubation in microgravity: a simulation study comparing direct laryngoscopy and videolaryngoscopy†

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This article is accompanied by an editorial: Spaceflight: the final frontier for airway management? by J Hinkelbein., *Br J Anaesth* 2020:125:e5–e6, doi: 10.1016/j.bja.2019.12.002

[†] This study was presented at the 90th Aerospace Medical Association Congress, Las Vegas NV, USA, on May 7, 2019, under the title 'Improving success of orotracheal intubation by novice operators in microgravity with videolaryngoscopy'; (European Society of Aerospace Medicine*PS44A44B″d*Clinical Space Medicine Panel).

Abstract

Background: The risk of severe medical and surgical events during long-duration spaceflight is significant. In space, many environmental and psychological factors may make tracheal intubation more difficult than on Earth. We hypothesised that, in microgravity, tracheal intubation may be facilitated by the use of a videolaryngoscope compared with direct laryngoscopy.

Methods: In a non-randomised, controlled, cross-over simulation study, we compared intubation performance of novice operators and experts, using either a direct laryngoscope or a videolaryngoscope, in weightlessness and in normogravity. The primary outcome was the success rate of tracheal intubation. Time to intubation and the confidence score into the success of tube placement were also recorded.

Results: When novices attempted to intubate the trachea in microgravity, the success rate of tracheal intubation using a videolaryngoscope was significantly higher (20/25 [80%]; 95% confidence interval [CI], 64.3–95.7 *vs* eight/20 [40%]; 95% CI, 18.5–61.5; P=0.006), and intubation time was shorter, compared with using a direct laryngoscope. In normogravity, the success rate of tracheal intubation by experts was significantly higher than that by novices (16/20 [80%]; 95% CI, 62.5–97.5 *vs* seven/25 [28%]; 95% CI, 10.4–45.6; P=0.001), but in microgravity, there was no significant difference between the experts and novices (19/20 [95%]; 95% CI, 85.4–100 *vs* 20/25 [80%]; 95% CI, 64.3–95.7; P=0.113). Higher confidence scores were achieved with videolaryngoscopy compared with direct laryngoscopy by both experts and novices in both microgravity and normogravity.

Conclusions: Videolaryngoscopy was associated with higher intubation success rate and speed, and higher confidence for correct tube placement by novice operators in microgravity, and as such may represent the best technique for advanced airway management during long-duration spaceflight.

Keywords: airway management; anaesthesia; microgravity; spaceflight; tracheal intubation; videolaryngoscopy

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Received: 1 October 2019; **Accepted:** 26 November 2019

Editor's key points

- Tracheal intubation in space using conventional direct laryngoscopy would be difficult.
- In simulated microgravity, the success rate of tracheal intubation using videolaryngoscopy was significantly higher than that using direct laryngoscopy.
- Videolaryngoscopy globally improved confidence score compared with direct laryngoscopy for all levels of expertise and all gravity conditions.
- Videolaryngoscopy may be useful for tracheal intubation in space under microgravity conditions.

Interplanetary human missions to the Moon or Mars are planned for the coming decades and will be associated with an increased risk of severe medical issues.[1,2] These missions will require complete medical autonomy as real-time support from Earth or evacuation will not be available. The risk of medical events requiring intubation during a 950-day mission to Mars with six crewmembers has been estimated to be greater than 2.5%.[3,4]

Oro-tracheal intubation may be required to conduct surgery or cardiopulmonary resuscitation, or in case of medical emergencies, for either primary pulmonary disorders or extrapulmonary affections. Its expertise is slow to acquire,[5] and numerous factors may undermine procedural performance during spaceflight. Intubation will likely be performed in an emergency situation by a non-anaesthetist or a non-doctor, facing fatigue and erosion of pre-flight skills.[6]

Previous research in weightlessness[7–10] unanimously confirmed very high failure rates for intubation by novice operators with direct laryngoscopy. In this context, videolaryngoscopy could represent an appealing device. It has been shown to improve intubation times and success rates, both in conventional hospital settings and difficult pre-hospital environments, especially for novice operators.[11–13]

We hypothesised that videolaryngoscopy could overcome the psycho-motor microgravity-related issues[14] and would ease intubation performance compared with direct laryngoscopy.

Methods

This study was authorised by the French National Space Agency (Centre National d'Etudes Spatiales [CNES]) ethical committee. We conducted a non-randomised, controlled, cross-over study comparing two groups of various expertise using two intubation devices under two gravity conditions: in weightlessness during parabolic flight and in normogravity after the flight.

Participants

Six subjects, three experts (with an experience of more than 1000 intubations) and three novices (with less than 10 intubations) participated in the experiment. Novices had a short airway management theoretical course and training 7 days before the first flight, during which they were familiarised with airway anatomy and intubation equipment and attempted two oro-tracheal intubations with videolaryngoscopy and two with direct laryngoscopy. All participants were volunteers and provided written informed consent for the research. All participants were medically certified to fly and were given subcutaneous scopolamine around 2 h before each flight (0.7–1.2 mg) to prevent motion sickness. All of the crew experienced zero gravity for the first time.

Simulating weightlessness

The study took place onboard the Novespace Zero-G A310 Airbus during the 55th French National Space Agency parabolic flight campaign. Each parabola consisted of about 25 s of hypergravity at 1.8 g, during which the plane accelerated upward at a 45° angle, then about 22–25 s of freefalling (simulated weightlessness), followed by another period of hypergravity corresponding to the recovery of the plane to the starting altitude.[15]

Mannequin and equipment

Tracheal intubation was performed using a high-fidelity full-body difficult airway training mannequin (SimMan ALS; Laerdal International, Stavanger, Norway) configured for difficult intubation. In space, astronauts experience cephalic congestion because of fluid shifting from the lower half of the body.[16] To reflect this, the tongue of the mannequin was inflated. We also restricted further cervical motion with a rigid collar (Stifneck Select, Laerdal International). Insertion of a 7.0 mm cuffed oro-tracheal tube was attempted using either direct laryngoscopy or videolaryngoscopy (McGrath model, Covidien™, Medtronic™), both fitted with a Macintosh size 3 blade.

In-flight experimental setup

Three flights were conducted, each offering 30 parabolas during which 30 microgravity intubations were attempted. After each flight, 30 normogravity attempts were performed inside the plane on the ground following the same experimental setup and sequence, for a total of 180 intubation attempts. Each flight boarded three operators. Two operators (one expert and one novice) sequentially performed five consecutive intubation attempts using either direct laryngoscopy or videolaryngoscopy before switching role and device.

The experimental setup is depicted in Figure 1. The mannequin was tethered to the cabin floor. The intubating operator was restrained to the floor in a sitting position, nearby the head of the mannequin. A third assistant timed the attempts and recorded all data on a paper chart.

Intubation sequence in weightlessness

Two operators (one expert and one novice) alternatively performed five consecutive, non-randomised intubation attempts by using direct laryngoscopy or videolaryngoscopy before switching position and device (Fig. 2). Each parabola offered 25 s of weightlessness, during which one intubation attempt was performed. Each parabola started with the intubating operator holding the device in his/her left hand. After entering weightlessness, the intubating operator inserted the device in the mannequin's mouth and attempted to expose the glottis. The assistant operator (an expert) handed the endotracheal tube to the right hand of the intubating operator, who then tried to insert it in the trachea. Each attempt ended whether after tube insertion or at the end of the free-floating period (Fig. 1). The time between parabolas (around 90 s) was used to

Fig 1. Intubation attempt during weightlessness, showing both operator and mannequin restrained to the floor of the airplane cabin. (Credit: Dr S. Rouquette, Novespace© and CNES.)

check the position of the tube and resetting the experimental setup by the assistant operator. The intubation operator vocalised his confidence score, then inflated the cuff and auscultated the chest during manual bag ventilation.

Intubation sequence in normogravity

A twin intubation study was performed on the same day by the crew after the flight and took place on the grounded plane at the airport. Normogravity records occurred after the microgravity records in order to avoid a training effect. Experimental settings, time for intubation, and cross-over sequences were identical to those in the in-flight study in order for gravity to be the only substituting variable.

Outcomes

Bi-pulmonary ventilation success was assessed by the intubating operator performing chest auscultation and by the measurement of a tidal volume on the mannequin's electronic sensors. Selective side intubation was considered as failure. The duration of each attempt was recorded and ended with vocal confirmation of tube placement from the intubating operator or at the end of the parabola. Finally, a subjective score of confidence in the correct tube placement was recorded after each attempt and ranked from 0 (no certainty about success or failure) to 10 (complete certainty in success or failure).

Statistical analyses

We choose to modelise the relation between different outcomes and variables with generalised linear mixed-effects models (GLMM); it is an extension to the generalised linear model (GLM), which takes into account random effects. These models are traditionally used for longitudinal data, such as measurements within successive parabolas.

The choice of this model is based on the possible learning effect that applied to each subject during the in-flight intubation sequences. Repetition of gestures for a given subject exposes the latter to a learning curve that excludes any hypothesis of independence between successive measurements regardless of the intubation technique used.

Intubation times were specifically measured based on the exclusion of trials that lasted more than the 25 s parabola period (n=160 trials instead of 180). Data were processed with

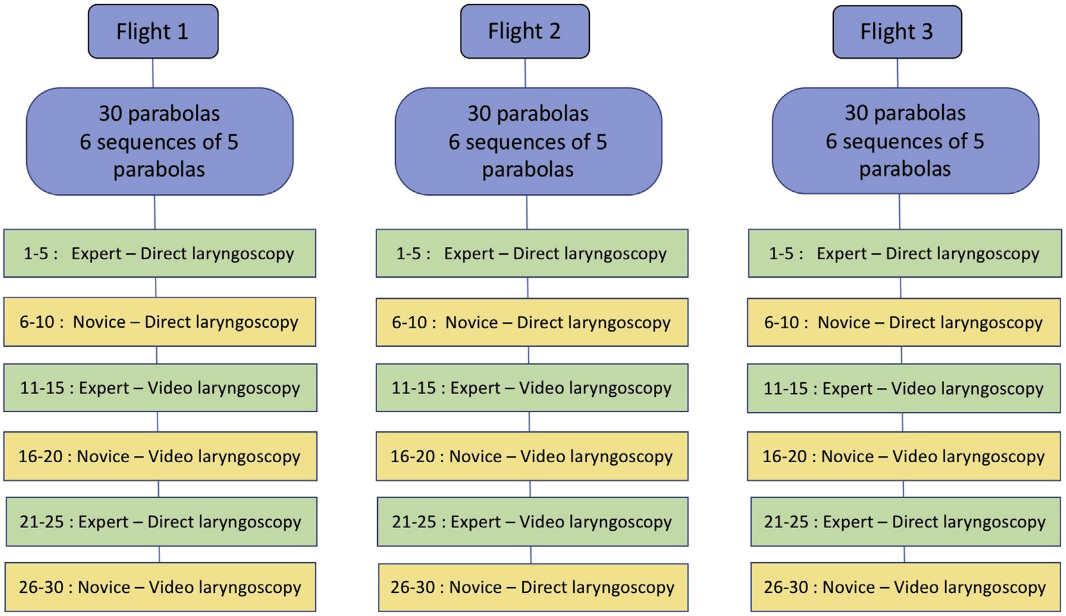

Fig 2. Flowchart of the microgravity intubations.

the R statistical software.[19] No statistical power calculation was conducted before the study. The sample size was dictated by the number of parabolas available, and the number of conditions to be tested. Then 95% confidence intervals (95% CI) were provided on percentages and means, with $P<0.05$ as the criterion of statistical significance.

Results

There were 180 intubations attempts. Experts performed direct laryngoscopy 50 times (25 in weightlessness, 25 in normogravity) and videolaryngoscopy 40 times (20 in weightlessness, 20 in normogravity). Novices performed videolaryngoscopy 50 times (25 in weightlessness, 25 in normogravity) and direct laryngoscopy 40 times (20 in weightlessness, 20 in normogravity). Experiment characteristics are detailed in Table 1.

Inter-individual analysis: comparing intubation by experts *vs* novices

The success rate for intubation with direct laryngoscopy was higher for experts than for novices, regardless of the gravity condition. Experts were also faster than novices at intubating, both in normogravity and in microgravity. The success rate for intubation with videolaryngoscopy was higher for experts than for novices in normogravity, but not in microgravity. Experts were faster than novices at intubating with videolaryngoscopy in all gravity conditions.

Intra-individual analysis: comparing the effect of device and gravity condition on operator performance

The use of videolaryngoscopy compared with direct laryngoscopy improved the success rate of intubation for novices only in microgravity, but not in normogravity. In microgravity, novices had shorter intubation times with videolaryngoscopy, but intubation times were not statistically different in normogravity.

The use of videolaryngoscopy improved the confidence score for tube insertion in all gravity conditions (Fig. 3). The score was consistently maximal for experts using videolaryngoscopy, and different from their score when using direct laryngoscopy, under both microgravity and normogravity conditions. For novices, using videolaryngoscopy was associated with very high confidence scores, higher than when using direct laryngoscopy, in both normogravity and microgravity.

Comparing success in experts *vs* novices

In this section, all models were fitted with the variable of interest (experts compared with novices) as a fixed effect and the individual as a random effect for each gravity condition. The model is adjusted with the trial order of intubation sequences (from one to five) as an added fixed effect, to control for potential training effect.

Odds ratios (ORs) are reported for binary outcomes (success or failure). The reported upper and lower bounds are for 95% CIs. Results are shown in Table 2.

Experts were always more successful than novices except when videolaryngoscopy was tested in microgravity. It was only under this condition that statistical difference was not found between the two groups.

Comparing confidence score with videolaryngoscopy *vs* direct laryngoscopy (in all gravity conditions)

In this section, all models were fitted with the variable of interest (videolaryngoscopy *vs* direct laryngoscopy) as a fixed effect and the individual as a random effect. The model is adjusted with the trial order (from one to five) as an added fixed effect, to control for potential training effect, and the experience of the individual (expert *vs* novice) as another fixed effect.

The result shows that videolaryngoscopy globally improves the confidence score compared with direct laryngoscopy (OR=3.65; 95 CI, 3.1–4.2; $P<0.001$) considering all levels of expertise and all gravity conditions.

Discussion

We have found that the use of a videolaryngoscope led to a higher success rate of tracheal intubation and confidence scores by novice operators in microgravity, despite hostile intubation conditions in a highly unfamiliar environment. A key finding is that the skill gap between novices and experts

Table 1 Global experiment results regarding device, expertise level and gravity conditions. sd, standard deviation.

Condition		Novice	Expert	P
Direct laryngoscopy outcome (%) in microgravity	Failure	12/20 (60.0)	1/25 (4)	<0.001
	Success	8/20 (40)	24/25 (96)	
Direct laryngoscopy certitude (mean [sd]) in microgravity		5.6/10 (3.1)	7.5/10 (2.2)	0.019
Direct laryngoscopy intubation time (mean [sd]) in microgravity				
Videolaryngoscopy outcome in microgravity	Failure	5/25 (20)	1/20 (5)	0.113
	Success	20/25 (80)	19/20 (95)	
Videolaryngoscopy certitude score (mean [sd]) in microgravity		9.9/10 (0.20)	10/10 (0.00)	0.377
Videolaryngoscopy intubation time (mean [sd]) in microgravity		15.20 (5.61)	10.93 (5.10)	0.013
Direct laryngoscopy outcome in normogravity (%)	Failure	12/20 (60)	4/25 (16)	0.003
	Success	8/20 (40)	21/25 (84)	
Direct laryngoscopy certitude score (mean [sd]) in normogravity		5.30 (2.66)	6.84 (2.54)	0.054
Direct laryngoscopy intubation time (mean [sd]) in normogravity		14.8 (3.9)	11.0 (4.0)	0.004
Videolaryngoscopy outcome (%) in normogravity	failure	18/25 (72)	4/20 (20)	0.001
	success	7/25 (28)	16/20 (80)	
Videolaryngoscopy certitude score (mean [sd]) in normogravity		9.9 (0.4)	10.00 (0.00)	0.377
Videolaryngoscopy intubation time (mean [sd]) in normogravity		15.6 (4.3)	9.9 (3.5)	0.001

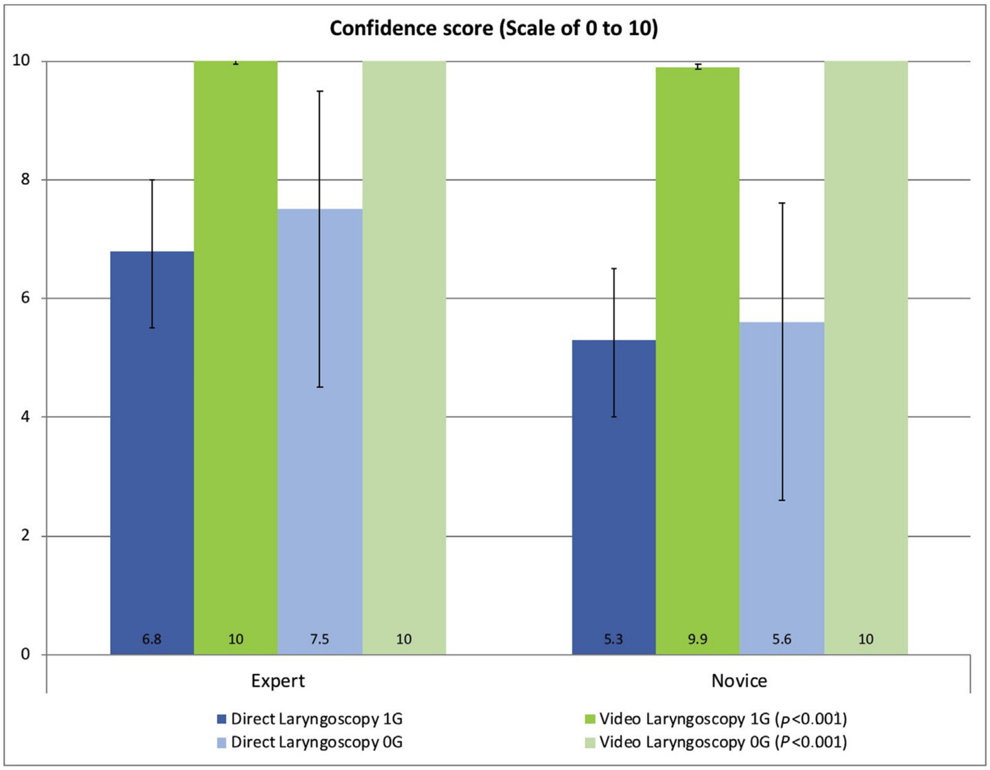

Fig 3. Intubation confidence scores for each experimental condition (*P<0.05). Use of videolaryngoscopy consistently led to maximal or near-maximal confidence scores for tube insertion.

appears to partially vanish when using videolaryngoscopy in weightlessness. This is an important discovery for the design of future medical kits and procedures for space missions.

Remarkably, it appears in this study that the benefit of videolaryngoscopy for novices revealed itself particularly well in microgravity. In post-flight normogravity procedures, novices had poorer scores when using either direct laryngoscopy or videolaryngoscopy despite the benefit of being trained by preceding microgravity intubations. This was most likely related to the difficult intubation conditions, which were described as challenging even by the experts.

Weightlessness changes the actual physical forces on the operator's body. Zero gravity (even tethered to the cabin floor) partially increases the degrees of freedom of the operator's sitting position, facilitating a more elongated position with the patient's mandibula–laryngoscope axis in order to perceive the glottis through the videolaryngoscopy video screen. An analogy can be made with the tracking system of a fighter plane, that allows the pilot to stay focused on his target independently from the aircraft's movements.[17] Moreover, after the glottic '*visual locking*', the operator can visually better control the patient's surroundings to schedule tasks associated with intubation. Further ergonomic studies would be useful to test these hypotheses.

Numerous factors may affect the safety of intubation when performed under an austere environment, including environmental hazards, poor ergonomics, lack of equipment and skills, and cognitive and physical impairment of caregivers. Microgravity also impairs eye–hand coordination, and central executive and psychomotor functioning.[14] It appears that many of these factors may be addressed or improved by the use of videolaryngoscopy, possibly allowing experts to regain control over the zero-gravity environment and therefore reaching quick intubation times. The shorter training time measured by others with videolaryngoscopy is a particularly appealing aspect, as very limited time will most likely be

Table 2 Comparing success in experts *vs* novices with a generalised linear mixed-effects model.

Experimental condition	Odds ratio	Lower 95% confidence interval	Upper 95% confidence interval	P value
Direct laryngoscopy in microgravity	34.8	5.5	689.3	0.001
Videolaryngoscopy in microgravity	4.7	0.6	99.0	0.178
Direct laryngoscopy in normogravity	28.5	3.6	5259.9	<0.0001
Videolaryngoscopy in normogravity	38.3	5.6	654.4	0.001

dedicated to airway management skills for non-medical crewmembers.[18] The high confidence scores obtained with videolaryngoscopy is a valuable finding which may improve safety and help shorten apnoeic time. Indeed, knowing with a high level of certainty that an attempt was unsuccessful (e.g. oesophageal intubation) may accelerate novel attempts or initiation of alternative oxygenation pathways.

Several limitations of this study can be highlighted. First of all, technical feasibility and clinical relevance are somewhat distinct. Although videolaryngoscopy may facilitate the technical realisation of the procedure, the device itself does not resolve the numerous issues related to the management of a critically ill or surgical patient in an extreme and remote environment. Next, our experimental setting does not realistically represent how long the intubation would take in a real-world scenario. For example, we did not account for the time needed to prepare all the equipment, restrain patient and operator, administer sedation, etc. Next, we did not test the free-floating condition (patient and operator untethered), which is likely to be the patient's initial configuration in case of a sudden on-board emergency. Previous research advised against attempting intubation in a free-floating condition because the success rates were very poor.[7] The short delay between the theoretical training and the simulation could be criticised, because it could have helped with recall. Finally, the study value is limited by the small number of participants. Another open point is the residual failure rate of 20% for first pass success in the novice group with the videolaryngoscope under microgravity conditions.

In conclusion, videolaryngoscopy appears to be better suited than direct laryngoscopy for performing endotracheal intubation in weightlessness, allowing novices to reach high—but not maximal—success scores and high confidence in the gesture. This represents valuable information when planning for medical contingencies during future long-duration space missions.

Authors' contributions

Study design and data collection: all authors.
Data interpretation: all authors.
Writing of the manuscript: all authors.
Data analysis: CS, ST, CB, FJ, TM, MK.
All authors reviewed and approved the final manuscript.

Acknowledgements

We gratefully acknowledge Pr. Ozier at the Anesthesiology and the Critical Care Department of the Brest Teaching Hospital for institutional support. We thank Yoann Le Mer and Yvon Thomas from Lorient General Hospital for their participation. We also gracefully acknowledge Frédéric Berhault, Anne-Clotilde Duchesne, Thomas Villatte, and Sebastien Rouquette from the CNES/Novespace for their support before and during the flights.

Declaration of interests

The authors declare that they have no competing interest. The medical equipment was graciously made available by their respective manufacturers.

Funding

Centre National d'Etudes Spatiales (CNES).

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Handling editor: Takashi Asai