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Manual vs Automated Ventilation with an i-gel® Airway During Short-Haul Helicopter Operations

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ABSTRACT

OBJECTIVES: Short-haul rescue involves evacuating a patient from a backcountry environment while suspended beneath a helicopter. Airway management may be required for head injuries or other critical transports. These missions may compromise airway security and ventilation quality. The objective of this study was to compare manual and automated ventilation performance during simulated static and live short-haul scenarios using a mid-fidelity manikin with an i-gel® airway.

METHODS: We used a prospective simulation-based, non-randomized crossover study design. The study included two scenarios: simulated static and live helicopter short-haul scenarios. An i-gel® airway was pre-inserted into a mid-fidelity Laerdal Quality Cardiopulmonary Resuscitation manikin. The primary outcome was achievement of target minute ventilation (MV; 5–7.2 L/min). Stretcher attendants performed two short-

haul tests for each scenario. The first test utilized a pocket bag-valve-mask for manual ventilation of the manikin and for the second an automatic ventilator was used. Tidal volumes, breaths per minute, and MV were measured. Additionally, post-test i-gel® movement was documented and each stretcher attendant completed a post-simulation operational usability survey. Paired comparisons between manual and automated ventilation were analyzed using McNemar's exact test for the primary outcome and Wilcoxon signed-rank tests for secondary outcomes.

RESULTS: Nine attendants completed both methods in the static scenario; six completed both in the live scenario. Target MV was achieved in 67% of tests via manual ventilation compared to 100% with automated during the static tests. In live scenarios, target MV was achieved via manual in 33% of tests while automated achieved 100%. This difference, while substantial, did not reach statistical significance (static: $p=0.25$; live: $p=0.12$) likely due to low number of tests with all discordant outcomes favoring the automated ventilator. Manual ventilation resulted in greater i-gel® movement and resulted in four ventilation disconnects (two static, two live) while no disconnects were observed during automated ventilation; participants also reported greater preference for automated ventilation.

CONCLUSIONS: Automated ventilation consistently achieved target MV, minimized i-gel® movement, and was preferred by attendants. Rescue teams should consider automated ventilation for short-haul airway management with an i-gel® airway.

Keywords: Airway Management, Rescue Work, Air Ambulance, Helicopter, Transportation of Patients, Emergency Medical Services

INTRODUCTION

Short-haul helicopter rescue is a technique used to extract patients and rescuers from terrain inaccessible to ground-based evacuation. Rescuers and patients are suspended beneath a helicopter and transported to a safe landing zone. Short-haul operations are frequently employed in technical terrain where rapid extraction can significantly reduce exposure time and risk for both patients and rescuers (1).

Short-haul rescue presents complex challenges for prehospital airway management. Wind turbulence, environmental factors, mechanical vibration, patient motion, and limited operator mobility can compromise stability of airway devices and ventilation quality (2–4). The International Commission for Alpine Rescue published guidelines on airway management in Human External Cargo (HEC) operations (5). However, the rarity of these cases provides limited evidence upon which to guide practice.

A Norwegian national search and rescue database identified only 54 intubated HEC operations among 2,423 missions between 2011 and 2024. Similarly, a 2018 systematic review identified just 34 documented cases over 17 years across five articles and one case report describing airway management before hoist or longline extraction. Data from Victoria, Australia reinforce this rarity: across 125 HEC missions conducted from 2010–2014, zero involved an intubated patient. Together, these findings highlight both the infrequency and the limited evidence surrounding advanced airway management during aerial extrication (5–7).

While endotracheal tubes (ETTs) remain the gold standard for definitive airway control, supraglottic airway devices (SGAs) such as the i-gel® are increasingly favored in search and rescue (SAR) operations due to their rapid insertion, minimal training requirements, and resistance to movement in austere conditions (8,9). Prior research has focused primarily on intubated patients during hoist operations and found that automated ventilators maintain more consistent tidal volumes (TVs) compared to manual bag-valve-mask (BVM) ventilation under dynamic conditions (3,10). However, no published studies have evaluated these ventilation methods using an SGA airway during live short-haul rescues.

We compared manual and automated ventilation performance during simulated static and live short-haul scenarios using a mid-fidelity manikin with an i-gel® airway. We hypothesized that manual ventilation would result in less reliable conditions and variable ventilations than with an automated ventilator.

METHODS

The project was conducted with Teton County SAR (TCSAR) Organization, a volunteer rescue organization serving under the jurisdiction of the Teton County Sheriff's Office. The team collectively performs 10,000 hours of rescue-related services every year.

This was a prospective simulation-based, non-randomized crossover study. The study was considered Non-Human Research by the University of Utah IRB (IRB_00189902). Manual and automatic ventilation were compared during static and live helicopter short-haul scenarios with a pre-inserted i-gel® SGA (Intersurgical Ltd, Berkshire, UK) placed in a mid-fidelity Resusci Anne® Quality Cardiopulmonary Resuscitation full-body AW manikin (Laerdal, Stavanger, Norway). The manikin was packaged into a StableFlight Heli-Bag (Life Support International Inc, Langhorne, PA, USA). An i-gel® was selected because this is TCSAR's primary airway device. The manikin was connected via Bluetooth to the QCPR app which tracked session duration, average TV, total breaths, and number of breaths that were below, within range, or high volume.

Two scenarios and a total of 30 tests were performed. A "scenario" refers to the static or live short-haul condition, and a "test" refers to an individual short-haul application of a single ventilation method (manual or automated). The static scenario (Figure 1) was performed first inside a hangar with a mechanical winch in which stretcher attendants were suspended four to five feet above the ground by a static rope. Each test lasted 4 minutes before lowering to the ground. The live scenario (Figure 2) was performed second and utilized an Airbus H125 helicopter and the Airbus H125 Boost HEC short-haul system with a 150' line (Boost Human External Cargo Systems, North Vancouver, BC, Canada). This scenario was performed at a landing zone at 6,240ft (1,901 m) above sea level in a practice area on United States (U.S.) Forest Service land in the Bridger-Teton National Forest, Wyoming. The helicopter lifted stretcher attendants and

the packaged manikin per typical short-haul operation, flew for 4 minutes in a large circle, then lowered personnel at the same location.

Nine team members participated in the static scenario and six team members participated in the live scenario. Participants were recruited as a convenience sample. Fewer participants were included in the live scenario due to time and helicopter operating cost restraints. Two of the nine for the static scenarios were Grand Teton National Park Rangers. All others were TCSAR rescuers. The static scenario included 1 emergency medical physician, 3 Emergency Medical Technicians (EMT), 1 registered nurse (RN), 3 paramedics, and 1 Wilderness First Responder (WFR). The live scenario included 3 stretcher attendants from the static day and 3 new stretcher attendants and consisted of 2 EMTs, 1 Paramedic, 1 RN, 1 Outdoor Emergency Care Responder, and 1 WFR. Prior automated ventilator experience varied by credential level, with the physician having the most extensive experience. However, all stretcher attendants had prior training with the automated ventilator used in this study and were familiar with manual bag-valve-mask ventilation through clinical or rescue training. The Grand Teton National Park Rangers carry the same resuscitator model used in this study on their ambulances and for backcountry response, and TCSAR personnel had trained with this device prior to the study, though not during live short-haul operations. All were current in training for short-haul operations and wore required personal protective equipment.

Each stretcher attendant participated in two ventilation methods for both the static and live short-haul scenarios. The first ventilation method was performed with the manikin

ventilated manually by hand using a manual bag (Pocket BVM; Micro BVM Inc., Montreal, QC, Canada). Stretcher attendants were instructed to ventilate using their dominant hand at a target 10–12 BPM with TVs of 500–600 mL or until observing visible chest rise.

In the second ventilation method, ventilation was automated using the O-Two CAREvent (Renew Biomedical, Jackson, TN, U.S.) set to 10 breaths per minute at 600 mL; stretcher attendants were instructed to monitor manikin chest rise and fall to ensure ventilator was performing as programmed.

Target minute ventilation (MV) for both methods was defined as $5-7.2 \text{ L/min}^{(11)(12)}$.

Nine stretcher attendants completed both methods in the static scenario; six completed both in the live scenario

I-gel® placement was verified, repositioned at the same depth, and recorded before the start of each trial. This was done by adhering a flexible tape measure along the shaft of the i-gel® and aligning the 5-cm mark with the manikin's incisors (Figure 3) before each session. Following each trial, the i-gel® was visually inspected, and any vertical deviation of the incisor contact point from the original 5-cm mark was measured and recorded as movement (in millimeters). Mounted cameras on the helmet of the stretcher attendant and chest of the manikin recorded every session for analysis by the research team.

After completing both manual and automated ventilation methods, each stretcher attendant completed a post-simulation operational usability survey. This brief Likert-style questionnaire assessed stretcher attendants' perceived ease of use, control of ventilation, physical demand, situational awareness, confidence, and overall suitability of each ventilation method for a short-haul i-gel® airway scenario. Respondents also indicated their preferred ventilation method and provided optional qualitative comments.

Variable of interest

The independent variable was the ventilation method (Manual vs. Automated). The primary outcome was the proportion of tests achieving the target MV (5.0–7.2 L/min). Secondary outcomes included TV (mL), ventilation rate (breaths/min), i-gel® supraglottic airway movement (mm), and participant method preference.

Statistical analysis

Descriptive statistics were calculated for all study variables. The primary outcome was the proportion of tests achieving the target MV (5.0–7.2 L/min). Differences in this success rate between manual and automated ventilation were compared using McNemar's exact test for paired binary data. Secondary outcomes included MV (L/min), TV (mL), ventilation rate (breaths/min), i-gel® supraglottic airway movement (mm), and participant method preference. Due to the small sample size, all continuous data are presented as a median and interquartile range (IQR). Comparisons between paired manual and automated ventilation measurements were performed using the Wilcoxon signed-rank test for all outcomes. All tests were two-tailed, and a p-value < 0.05 was

considered statistically significant. Analyses were conducted separately for the static and live helicopter scenarios using R version 4.3.1.

RESULTS

Static Scenario

The static simulation scenario took place in an enclosed hangar with a controlled environment under calm conditions and warm temperatures.

Nine stretcher attendants (N = 9) completed the static simulation scenario.

Under static conditions, the primary outcome of achieving target MV is presented in Table 1. Manual ventilation achieved target MV in 67% of tests (6/9) compared to 100% (9/9) for automated ventilation ($p=0.25$). For secondary outcomes, as shown in Table 1, manual ventilation demonstrated less consistency and control than automated ventilation. As shown in Table 1, manual ventilation produced significantly lower MV (median 5.66 L/min (4.40 – 6.23) vs 6.30 L/min (6.20 – 6.57); $p = 0.04$) and TVs (544 mL (516 – 569) vs 681 mL (668 – 695); $p = 0.008$). Ventilation rate was slightly higher with manual ventilation (10.36 (9.27 – 11.67) vs 9.36 (8.59 – 9.85); $p = 0.03$). I-gel® movement remained minimal and non-significant (Table 1). Two disconnects occurred during a sudden rapid release of the rope with manual ventilation and none during automated; all were quickly corrected.

Live Scenario

The live helicopter short-haul scenario took place from 0900-1200 on a calm and stable weather day. Reported wind conditions varied and ranged between 5-10 knots with gusts of up to 10 knots out of the North or East.

Six stretcher attendants (N = 6) completed the live scenario. For the primary outcome, manual ventilation achieved target MV 33% of tests (2/6) compared to 100% (6/6) for automated ventilation ($p=0.12$, McNemar's exact test). All discordant outcomes favored the automated device.

During live short-haul helicopter scenarios manual ventilation yielded significantly lower MV compared to automated ventilation (4.44 L/min (4.10 – 5.00) vs; 6.68 L/min (6.40 – 6.80) $p = 0.03$), lower TVs (607 mL (573 – 630) vs 696 mL (678 – 704); $p = 0.04$), and lower ventilation rates (7.5 (6.6 – 8.3) vs 9.5 (9.4 – 9.7) breaths/min; $p = 0.03$). i-gel® movement was greater under manual ventilation, showing a trend toward significance ($p = 0.05$) (Table 2). Two disconnects occurred during manual ventilation and none during automated; all were quickly corrected.

Stretcher Attendant Survey

Stretcher attendants completed a post-simulation operational usability survey after the static and live scenarios. All stretcher attendants provided paired responses comparing the two ventilation methods across six usability domains: ease of use, perceived control of ventilation, physical demand, situational awareness, confidence, and overall suitability for a short-haul i-gel® airway patient.

Across all respondents, automated ventilation received better median scores in all six domains. When asked for a preferred ventilation method, 8 of 9 (89%) stretcher attendants favored the automated device citing improved stability, ease of multitasking, and reduced workload.

The single stretcher attendant who preferred manual BVM noted greater perceived control using the manual ventilation method. The attendant acknowledged increased difficulty managing the bag during peak workload periods.

Stretcher attendants' qualitative comments highlighted that automated ventilation simplified operation, reduced physical demand, and allowed better focus on surroundings, several noted concern regarding troubleshooting capability in case of device malfunction mid-flight and lack of direct feedback of ventilation quality.

DISCUSSION

We found that automated ventilation provided more consistent and effective respiratory performance compared to manual ventilation with an SGA during static and live short-haul scenarios. For the primary outcome, automated ventilation demonstrated perfect reliability (100% success), a substantial improvement over manual ventilation. Although McNemar's test did not yield a statistically significant p-value—a result strongly influenced by the small sample size—the clear direction of all discordant outcomes provides compelling evidence of its practical superiority in this setting. These findings

show the potential for automated ventilation to improve airway management during short-haul rescues. This study is the first to assess i-gel® airway during short-haul operations.

Manual ventilation is vulnerable to interruptions in rate and volume because stretcher attendants must manage task load, divided attention, and aircraft movement. These factors likely explain the variability seen between static and live scenarios. In contrast, automated ventilation delivered consistent preset volume breaths in both scenarios, unaffected by environmental conditions or stretcher attendant. This consistency suggests that automated systems may reduce the risk of hypo- or hyperventilation in the motion-intensive and operationally demanding conditions of short-haul operations.

For short-haul teams with limited resources, manual ventilation can still be a viable option. Prehospital clinicians should, however, be appropriately trained and have real-world operational exposure to these conditions. Rescuers should be aware that the tendency may be to under ventilate using manual ventilation, as both lower rates and TVs were noted in our study during live scenarios. Training could include instructions to compress the bag fully to result in adequate TV. Incident command and medical advisors could provide audible cues instructing rescuers to maintain an appropriate rate. Specific training targeting operational techniques may mitigate the effects of task management demands, environmental instability, and divided attention inherent to live scenarios. This guidance may assist with maintaining appropriate ventilation with manual methods.

The four disconnections during manual ventilation underscore the unstable and changing environment during short-haul operations. The two disconnections that occurred during a rapid release in the static scenario demonstrate the difficulty of maintaining the BVM and i-gel® connection when jarring movements happen in real flight; wind shear, turbulence, or hard landings could produce these conditions. A 6-inch section of respiratory tubing between the BVM and the i-gel® or ETT could minimize these effects but would also increase dead space with unclear but likely minimal clinical significance.

Automated ventilation provided greater stability and less movement of the SGA. This advantage likely results from the automated ventilator being secured to the rescue litter and moving in unison with the patient; manual ventilation requires the attendant to maintain their arm position close to the airway during periods of significant movement. These positional differences may explain the increased risk of i-gel® movement and reinforce the ergonomic benefit of automated systems in short-haul operations.

Manual ventilation placed increased cognitive and physical demands on the stretcher attendants. Two video-documented incidents illustrated these risks: in one, a stretcher attendant released the bag to stabilize a spinning rescue litter; in another, a stretcher attendant adjusted harness height for better positioning, again requiring both hands and relegating the priority of ventilation. These events highlight the human factors risk associated with competing task demands during manual ventilation in short-haul

operations. In both cases, a circuit disconnection leading to a dropped bag could have left the patient without ventilation for the duration of the flight. We recommend clipping a tethering cord to the attendant linking the BVM to the stretcher attendant to mitigate this hazard.

Attendants reported that automated ventilation allowed greater focus on patient safety, rigging verification, and overall situational awareness without reducing ventilation quality. The one participant who preferred manual ventilation mentioned the tactile feedback provided reassurance that adequate breaths were being delivered, something they felt was diminished with automated ventilation. Two additional participants noted concerns of how a ventilator failure would be managed during short-haul and ability to troubleshoot if this was to occur. These concerns could be mitigated by specific training on methods to visually monitor the ventilator to ensure proper ventilation and function. Teams could consider possibly carrying a BVM as a rescue device in case the ventilator fails due to cold or other austere conditions.

Although the participant who preferred manual ventilation was a paramedic, other participants, including a physician and other paramedics with exposure to multiple ventilator models, did not favor manual ventilation. Preference appeared to reflect individual comfort and perception of control rather than credential level. Structured training with automated ventilators in live short-haul scenarios is likely to improve prehospital clinician comfort and confidence among rescue team members.

Our findings align with prior work examining challenging ventilation techniques during HEC operations. Burns et al. described bag-valve-mask failure due to rotor downwash and subsequently demonstrated that downwash can collapse manual BVMs during manikin testing (3). Lavon et al. reported stable ventilation with automated devices during hoist missions involving intubated patients (2). Hollott et al. found that automated ventilators outperformed manual ventilation in manikin-based hoist studies measuring airway pressures (10). Our study expands on this literature by evaluating short-haul operations and by demonstrating benefits using a supraglottic airway, similar to actual use in many SAR and prehospital emergency medical organizations

While conditions during our scenarios and tests were generally favorable, rescues frequently occur at high altitude and in cold and windy environments where both patients and rescuers must wear multiple insulating layers. These layers reduce visibility of the chest and make it more difficult to assess chest rise and fall. Gloves, while necessary for thermal protection, may limit grip on the bag and make manual bag-valve-mask ventilation and airway device manipulation more challenging. High winds further increase wind chill and can complicate both patient contact and ventilatory control.

These environmental factors include cold stress, reduced dexterity, limited visibility, and unstable working platforms; all increase the challenge of advanced airway management during hoist, longline, and short-haul operations. Such conditions should be considered when comparing our relatively warm and calm study environment to real-world rescue missions. Ventilation challenges may, in fact, be more magnified and dramatic.

Future work should evaluate HEC ventilation methods in different environmental and seasonal conditions and include larger studies involving other SAR organizations.

Additional research comparing other airway devices and assessing human-factors (e.g., task load, situational awareness, communication) will help support real-world implementation.

LIMITATIONS

Limitations include small sample size; the limited number of observations reduced statistical power, particularly for the primary binary outcome. The non-significant p-values for the difference in target MV achievement rates (manual 67% and 33% vs. automated 100%), despite the clear clinical trend, are a direct consequence of this limited power.

Operator variability may have also influenced the results. Stretcher attendant experience level, physical strength, or prior exposure to the equipment did not limit inclusion which could influence the outcomes. Three of the six live scenario stretcher attendants had not participated in the preceding static tests, while the remaining three had prior familiarity. This uneven exposure may have contributed to performance differences, and the order in which methods were performed may have introduced learning or observational bias.

The mid-fidelity manikin estimates TVs from chest rise detected by an internal sensor. Although we examined for external compression from the litter and technique, TVs could have been altered due to these factors.

CONCLUSIONS

Automated ventilation provided more consistent and effective respiratory performance than manual BVM ventilation via SGA in both static and live helicopter short-haul scenarios. It achieved target ventilation with perfect reliability (100% success) across all tests while manual ventilation was inconsistent. These findings suggest that automated ventilation may enhance airway control and reduce variability during HEC rescue operations, though larger clinical studies are needed to confirm these benefits.

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DATA SHARING STATEMENT: The data that support the findings of this study are available from the corresponding author, WQ, upon reasonable request.

AUTHORSHIP STATEMENT: Initial project concept conceived by Scott McIntosh and AJ Wheeler III. Study design, planning, and coordination led by Wade Quilter, TJ Hartridge, and Scott McIntosh with help from Albert Wheeler III, Eric Swanson, and Jared Katz. Simulations and data collection were carried out by the above-mentioned research team. Emad Awad performed the statistical analysis. All authors contributed to the interpretation of the results. Wade Quilter took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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Figure 1: Static Scenario

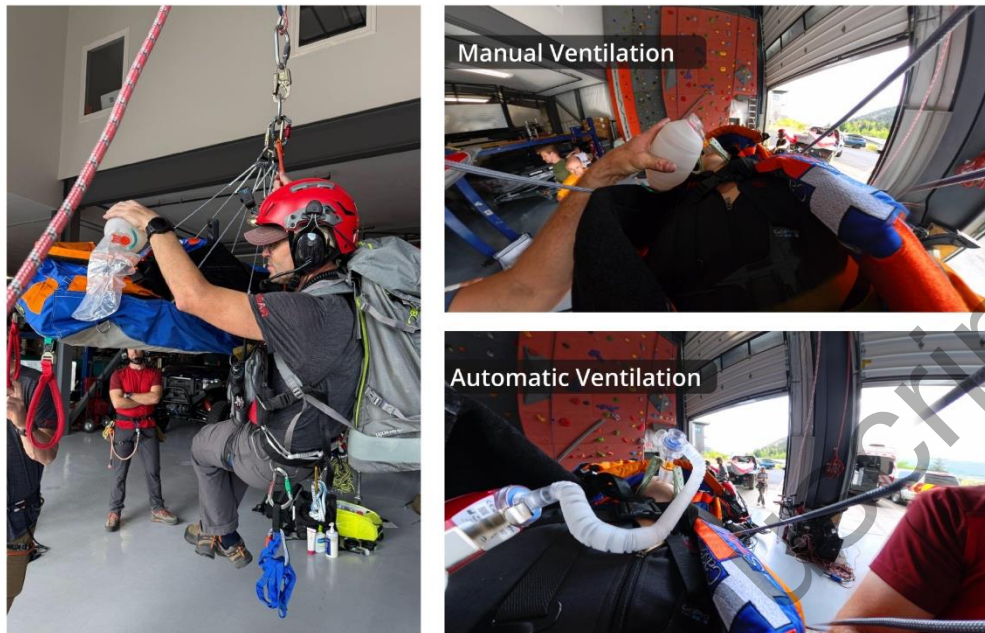


Figure 1 footnotes: Observer point of view during manual ventilation (left). Chest-mounted camera views during manual ventilation (top right) and automated ventilation (bottom right).

Figure 2: Live Scenario

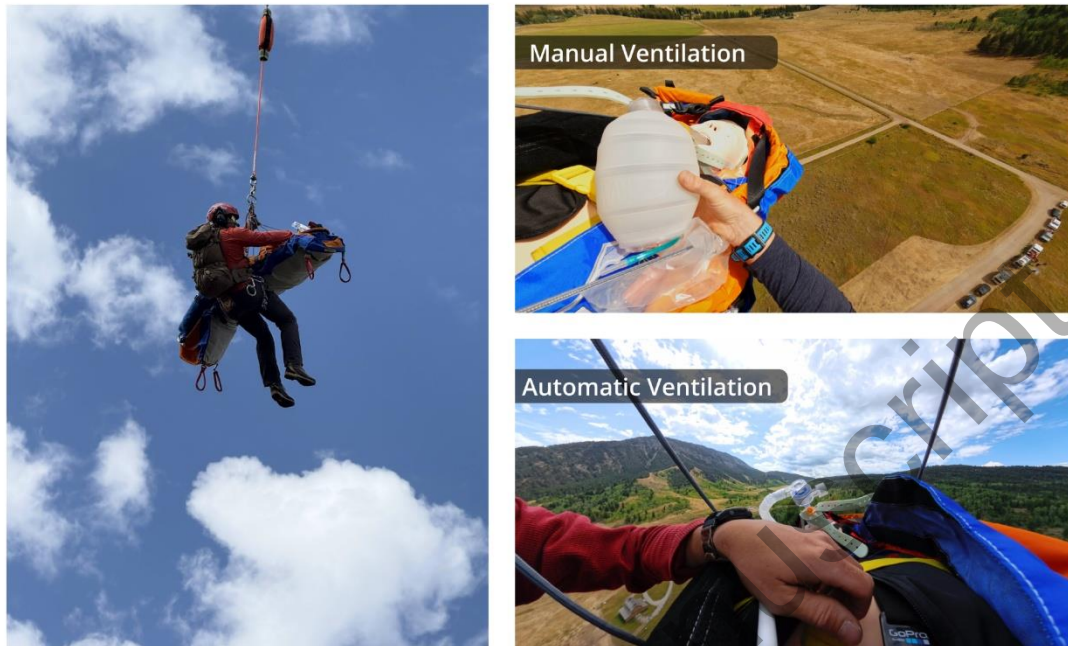


Figure 2 footnotes: Observer point of view from ground during manual ventilation underneath helicopter (left). Head mounted view during manual ventilation (top right) and chest mounted camera view during automated ventilation (bottom right).

Figure 3: i-gel® setup and depth verification.



Figure 3 footnotes: Manikin with the i-gel® placed and BVM connected (Left).

Measurement tape adhered to the i-gel® shaft illustrating how the incisors were used to confirm consistent insertion depth and assess post-test movement (Right).

Table 1: Ventilation performance in the static scenario (N = 9)

Variable	Manual Ventilation	Automated Ventilation	p- value
Achieved Target MV, n (%)	6 (67%)	9 (100%)	0.25
Minute Ventilation (L/min)	5.66 (4.40 - 6.23)	6.30 (6.20 - 6.57)	0.04
Tidal Volume (mL)	544 (516 - 569)	681 (668 - 695)	0.008
Ventilation Rate (BPM)	10.36 (9.27 - 11.67)	9.36 (8.59 - 9.85)	0.03
I-gel® Movement (mm)	0.0 (0.0 - 0.3)	0.00 (0.0 - 0.0)	1.8

Table 1 footnotes: Data for continuous variables presented as median (IQR); p-values from Wilcoxon signed-rank test, except for 'Achieved Target MV' (McNemar's exact test)

Table 2: Ventilation performance in the live helicopter scenario (N = 6)

Variable	Manual Ventilation	Automated Ventilation	p- value
Achieved Target MV, n (%)	2 (33%)	6 (100%)	0.12
Minute Ventilation (L/min)	4.44 (4.1 – 5.0)	6.68 (6.4 - 6.8)	0.03
Tidal Volume (mL)	607 (573 - 630)	696 (678 - 704)	0.04
Ventilation Rate (BPM)	7.5 (6.6 - 8.3)	9.5 (9.4 - 9.7)	0.03
i-gel® Movement (mm)	0.25 (0.13 - 0.38)	0.0 (0.00 - 0.09)	0.05

Table 2 footnotes: Data for continuous variables presented as median (IQR); p-values from Wilcoxon signed-rank test, except for 'Achieved Target MV' (McNemar's exact test).

Table 3: Video Analysis

Operational Factor	Findings
Ventilation Disconnects	The two static scenario disconnects occurred during a sudden release of the rope. The two live scenario disconnects occurred from excessive arm movement of the stretch attendant
i-gel® Movement	Visible i-gel® movement occurred more frequently during takeoff and landing. Movement typically appeared as lateral shifting within the manikin's mouth due to the bag pulling on the i-gel®.
Operational Demands	Short-haul operations imposed a physical burden and required competing motor tasks during manual ventilation, including (1) sustained arm abduction to ventilate during flight, (2) continued bagging while adjusting harness height, (3) continued bagging while maintaining upright body positioning during takeoff and landing, and (4) coordinated movement with the stretcher before and after takeoff when drift occurred.
Task Interference	In two manual method live trials, attendants temporarily released the ventilation bag: once to stabilize a spinning rescue litter and once to adjust harness height. In both instances, the ventilation device was left unsupported. Additional footage showed attendants intermittently

	shielding the i-gel® with their hands to protect it from rotor-wash and high wind exposure.
Workload Indicators	Multiple segments showed attendants performing one-handed ventilations while simultaneously managing haul-line slack or maintaining body stabilization, indicating a substantial multitasking burden during short-haul transport.

Table 3 footnotes: Video analysis was conducted using two camera mounts: one on the stretcher attendant's helmet and one chest-mounted on the manikin. Videos reviewed by research team