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ORIGINAL RESEARCH

Military

A translational study evaluating a ruggedized portable oxygen concentrator versus an oxygen cylinder in simulated polytrauma intubation of swine

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Abstract

Objectives: Portable oxygen concentrators (POCs) are medical devices that use filters to selectively remove nitrogen from ambient air to produce concentrated, medical-grade oxygen. This is the first study to evaluate a ruggedized POC's performance during simulated polytrauma intubation.

Methods: Twenty-seven swine were intubated and anesthetized with ketamine. At $T = 0$, animals were extubated, received a chest wall injury, a tibia fracture, and 20% total blood volume controlled hemorrhage was initiated. At $T = 10$ min, the swine were pre-oxygenated using a bag-valve mask connected to one of three randomized oxygen sources: (1) a ruggedized POC, (2) a M-15 oxygen cylinder, or (3) room air (control). At $T = 12$ min, animals were re-intubated to simulate polytrauma intubation and connected to the test oxygen source for the remainder of the experiment. Surviving animals entered a 2-h period where partial pressure of oxygen (PaO_2), oxygen saturation (SpO_2), and regional oxygen saturation (rSO_2) were monitored. Groups were compared using analysis of variance (ANOVA), Fisher's exact, log-rank analysis, or mixed-effects model as appropriate.

Results: All animals survived except one in the POC group. Mixed-effects models revealed differences between groups with regards to PaO_2 ($p < 0.0001$) and SpO_2 ($p = 0.006$). Based on post hoc analysis, oxygen cylinder PaO_2 was superior to both POC and control, but there were no differences between POC and control PaO_2. There were statistically and clinically significant differences in SpO_2 during periods of pre-oxygenation ($T = 10$–12 min), intubation ($T = 12$–14 min), and immediately after intubation ($T = 14$–20 min). The POC battery was consumed in 43 ± 13 min.

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Conclusion: In our swine model, a single, ruggedized POC provided inferior amounts of oxygen supplementation compared to an oxygen cylinder and performed no better than room air.

KEYWORDS
hypoxia, intubation, oxygen, portable oxygen concentrator, swine, trauma

1 | INTRODUCTION

1.1 | Background

Hypoxia is associated with a significant increase in mortality in trauma patients, such that if a patient with a traumatic brain injury become hypoxemic, there is a >200% increase in mortality.[1] Providing supplemental oxygen is a fundamental principle of trauma management and is highlighted as a standard-of-care intervention in Advanced Trauma Life Support and Tactical Combat Casualty Care.[2] In high-resource areas, distribution and use of oxygen outside of hospitals is largely reliant upon oxygen gas cylinders. During deployed military operations or rural emergency medical services (EMS); however, providing supplemental oxygen with compressed gas oxygen cylinders is challenging.[3] Oxygen cylinders are heavy, contain a limited volume, and are reliant upon austere logistics for resupply.

Portable oxygen concentrator (POC) technology has been suggested as an alternative to oxygen cylinders in low-resources setting, such as combat or search and rescue.[4] Unlike bulky chemical oxygen systems, or reliance upon a network of oxygen cylinders, POCs can provide a continuous low flow of oxygen by concentrating oxygen from ambient air.[5] POCs have already been deployed with American and international military units.[5–10] However, there is no available translational or clinical data to guide the use of POCs in low-resource trauma intubations.[3]

1.2 | Importance

Care during austere or combat operations requires medical interventions to be "man-portable," defined by the United States military as weighing less than 14 kg.[11] This greatly limits the size, oxygen flow, and battery life of ruggedized POCs. The majority of man-portable POCs currently hand-carried by US forces and are limited to 3L/min oxygen flow and 1–2 h of battery life.[6] These limitations raise serious questions about POCs during resuscitation of traumatically injured casualties in austere environments.

1.3 | Goals of this investigation

To inform decision makers in austere and military resuscitation, we performed a pragmatic, translational research study to compare oxygenation from a man-portable POC, an M-15 oxygen cylinder ("D-tank"), and a control group with no oxygen supplementation. Given the difficulties of researching trauma intubations in extremely austere and combat environments, we selected a swine model of polytrauma for this translational research. Our goal was to evaluate oxygenation and device performance during a high-risk trauma intubation and throughout a 2-h period of simulated, low-resource care. We wished to determine the performance of the SAROS 3000 Oxygen System, a POC commonly deployed by the US military (1–3 L/min, continuous mode) compared to the standard high-resource oxygenation intervention (1–15 L/min from an M-15 oxygen cylinder) and the current austere capability (no oxygen supplementation).

2 | METHODS

2.1 | Study design

The local Institutional Animal Care and Use Committee approved this research (protocol #FWH20220122AR). All research participants obtained appropriate training through the American Association for Laboratory Animal Science, and animal care was performed in strict compliance with the Guide for the Care and Use of Laboratory Animals in a facility accredited by AAALAC, International. Healthy, castrated male and non-pregnant female Yorkshire-Landrace (Sus scrofa) were allowed to acclimate for 5–7 days in temperature and light controlled pens with access to environmental enrichment. Animals weighed between 57 and 75 kg and were fasted the night before the experiment. The overall study design is illustrated in Figure 1.

A new POC (SAROS 3000 Oxygen System; CAIRE Inc.) was procured, inspected by a US Air Force biomedical equipment specialist, and was fully charged prior to experimental use. A mass spectrometry medical gas analyzer (MATE MGA 1100, MA Tech Services) confirmed the high quality POC output in its test conditions: 94.5% O_2, 0.3% N_2, 0.0% CO_2, and 5.15% argon. The M-15 O_2 cylinders were pressurized to 2000 pounds per square inch (PSI) prior to experimental use. Experiments were performed at an elevation of 692 ft.

2.2 | Animal preparation

Animals were premedicated with 6.6 mg/kg intramuscular tiletamine/zolazepam (Zoetis) and 0.01–0.05 mg/kg of intramuscular

buprenorphine. Once intravenous access was obtained a 100 mg ketamine bolus was given followed by 10–36 mg/kg/h ketamine infusion titrated by veterinary personnel. SpO_2 sensors were placed on the right front hoof. Subjects were then orally intubated and, to ensure pre-experimental respiratory health, underwent an oxygenation challenge where an SpO_2 >92% was required for 3 min while breathing room air before ventilatory support to be considered for the study. Animals that failed the oxygenation challenge were not enrolled in the study. If animals passed the oxygenation challenge, they were mechanically ventilated with tidal volumes (TV) of 7–10 mL/kg, a positive end-expiratory pressure of 5 cmH_2O, and a respiratory rate of 10–15 breaths/min, titrated to maintain end-tidal CO_2 ($ETCO_2$) of 35–45 mmHg. Each subject received 15 mL/kg bolus of warm 0.9% sodium chloride intravenously to ensure euvolemia.

All vascular access was obtained via Seldinger technique under ultrasound guidance. Both external jugular veins were cannulated via an 8.5-Fr sheath (Arrow-Flex; Teleflex). The right carotid was cannulated with a 5-Fr arterial line (Micropuncture Kit, Cook) to monitor for proximal aortic blood pressure and the left femoral artery was cannulated with an 8.5-Fr sheath for arterial blood sampling. Near-infrared spectroscopy (NIRS) sensors (Medtronic) were placed on the left pectoralis, the left thigh, and over the left kidney to measure regional oxygen saturation (rSO_2).

The Bottom Line

This study evaluated ruggedized portable oxygen concentrator (POC) performance during polytrauma intubation. Swine were randomized to receive oxygenation from: (1) a POC, (2) an oxygen cylinder, or (3) room air. There were statistically significant differences in partial pressure of oxygen ($p < 0.0001$) and oxygenation saturation ($p = 0.006$) in favor of the oxygen cylinder. Results showed that the POC underperformed the oxygen cylinder across a variety of oxygen parameters and provided marginal benefits compared to room air. Given weight and battery restrictions, we believe that man-portable POCs have limited utility when hand-carried into austere or combat conditions.

After initial set up was completed and baseline labs were obtained, animals' ventilator settings were weaned down (progressive reductions in TV and pressure support over appropriately 5 min) until the animals were spontaneously breathing 30% FIO_2 for at least 5 min.

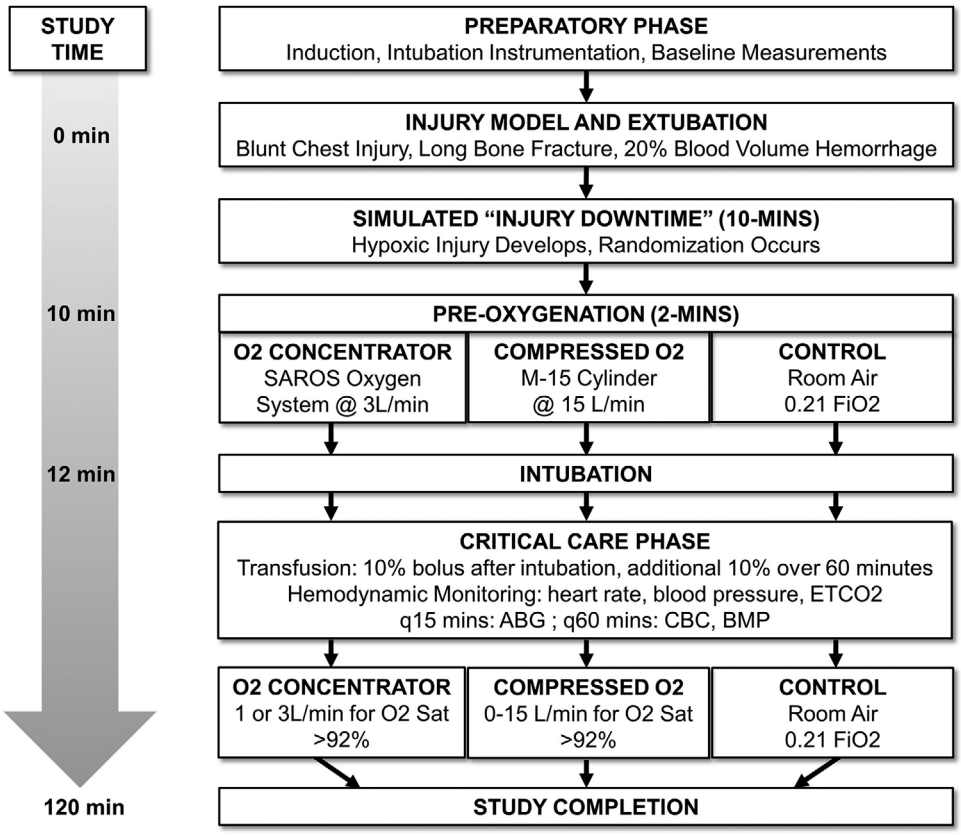

FIGURE 1 Experimental design. Injury and extubation occurred at $T = 0$ min. Randomization occurred at $T = 5$ min. Pre-oxygenation at $T = 10$ min was performed using a custom bag-valve mask connected to the randomized oxygen source. Intubation occurred 2 min later ($T = 12$ min) and the animal remained on that oxygen source until either the battery or cylinder was consumed. See Section 2 for additional details.

2.3 | Simulated injury, hemorrhage, and randomization

At $T = 0$ min, the swine were simultaneously extubated, a custom 4-in plate captive bolt gun was fired against the right chest wall, a 0.22 caliber powder actuated tool (Ramset Mastershot, Powder Level 3) was fired twice against the right tibia, and a controlled hemorrhage of 20% total blood volume (TBV) was initiated from the venous 8.5-Fr sheath. The hemorrhage continued for 10 min until completed. Hemorrhage was paused for 60 s if mean arterial pressure (MAP) dropped below 30 mmHg. After 60 s, if the MAP was above 35 mmHg, hemorrhage was reinitiated per the prior protocol and reassessed every 60 s during hemorrhage. If after 60 s, the MAP remained below 35 mmHg, no further hemorrhage was performed unless the MAP improved. Hemorrhaged blood was collected and stored into blood-collection bags containing citrate-phosphate-dextrose-optisol (Terumo Medical) solution for later re-transfusion.

To prevent animal demise before randomization, if the animal was not spontaneously breathing immediately after extubation, veterinary and research personnel provided bag-valve mask (BVM) ventilations, as needed, for the first 2–3 min after injury using a custom cone with rubber gaskets designed to mimic a human BVM–seal interface. After 5 min of hemorrhage, animals were randomized to one of three oxygenation groups via random envelope selection[12]:

- Experimental group: portable O_2 concentrator
- High resource oxygenation: M-15 O_2 cylinder
- Control: room air

2.4 | Pre-oxygenation and intubation

At T = 10 min, animals were provided bag-valve ventilation above their spontaneous respirations at 10 breaths/min for 2 min for pre-oxygenation before intubation. The custom bag-valve mask was connected to the oxygenation source the animals were randomized to receive (3 L/min by POC in continuous mode; 15 L/min from O_2 cylinder; or room air). At T = 12 min, the animals were re-intubated by veterinary personnel using an 8.0 endotracheal tube. If multiple intubation attempts were required, the animals were bagged for 30 s using the randomized oxygen source between attempts.

2.5 | Post-intubation

After the animals' re-intubation and during the 120-min critical care phase, interventions were designed to mimic austere capabilities. All subjects were placed on a ventilator (Impact 731 EMV+ Ventilator, Zoll) connected to the randomized oxygen source through a low-flow setup, as shown in Figure 2. Each oxygen source was titrated to maintain a goal arterial oxygen saturation (SaO_2) >92% and was reassessed every 5 min during the critical care phase. The POC was set at either 1 or 3 L/min in continuous mode and was used until the battery was consumed with no further supplemental oxygen. The M-15 oxygen cylinder was titrated between 1 and 15 L/min. The control group was ventilated using only room air.

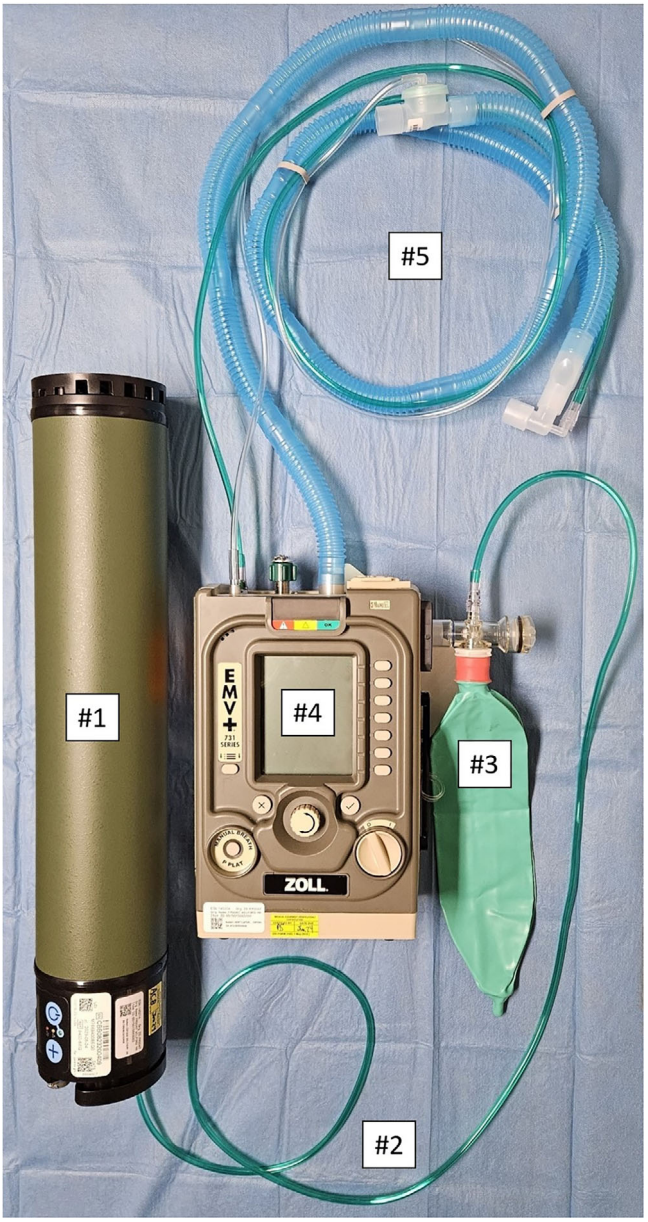

FIGURE 2 Low flow oxygen setup. Portable oxygen concentrator (#1). Oxygen tubing (#2) connects to a low-flow reservoir (#3) of the ventilator (#4). Finally, the ventilator is connected to the patient using ventilator circuit (#5).

At T = 15 min, a right-sided 36-Fr chest tube was inserted and placed on continuous suction for presumed right-sided pneumothorax. Subjects were transfused half of their previously removed blood (10% TBV) as a 10-min bolus after re-intubation and the second half (10% TBV) over a 60-min period.

Continuous heart rate, systolic, diastolic, mean arterial blood pressure, $ETCO_2$, SaO_2, and rSO_2 data were collected. Arterial blood gasses (ABGs) were drawn every 15 min. According to the TCCC guidelines,

hypocalcemia was corrected via predetermined protocols. No vasoactive medications were given as these are not typically available during austere or combat conditions.

2.6 | Outcomes

The primary outcome of this study was mean partial pressure of oxygen (PaO_2) from ABGs drawn during the 2-h period of prolonged field care (PFC). Pre-determined secondary outcomes include differences in SpO_2, rSO_2, and time to supplemental oxygen device consumption.

2.7 | Data analysis

Data are presented as mean ± standard deviation for continuous variables and fraction (%) for categorical variables. Groups were compared using analysis of variance (ANOVA), Fisher's exact, log-rank analysis, or mixed-effects model as appropriate. Differences between groups were considered significant when $p < 0.05$. Tukey's analysis was used to correct for multiple comparisons. A priori power analysis was performed for a one-way ANOVA by assuming a large effect size of 0.67, alpha set at 0.05 and beta at 0.20 resulting in a total of 27 animals (nine per group). Statistical analysis was performed using commercial software (GraphPad Prism 10).

3 | RESULTS

3.1 | Baseline characteristics

A total of 31 animals were used in this study: three were used for model development, 27 (nine per group) were included for analysis, and one additional animal was excluded, as it expired prior to randomization. Prior to experimental injury, there were no significant baseline differences among groups with regard to weight, sex, hemodynamics, or laboratory results (Table 1).

3.2 | Pre-randomization downtime

Across all animals, following injury and extubation but prior to randomization, SpO_2 rapidly fell to an average of 42 ± 17% and MAP averaged 44 ± 15 mmHg. There were no significant differences between groups prior to re-intubation. At randomization ($T = 5$ min), SpO_2 was 62 ± 26, 69 ± 14, and 68 ± 11% for the POC, oxygen cylinder, and control, respectively ($p = 0.7134$). Just before re-intubation ($T = 10$ min), SpO_2 was 66 ± 22, 83 ± 8.3, and 70 ± 18% for the POC, oxygen cylinder, and control, respectively ($p = 0.1649$). One animal was excluded from the study due to an asystolic cardiac arrest during the "injury downtime" period prior to randomization.

3.3 | Intubation times and overall survival

There were no statistically significant differences in time to intubation, intubation attempts, or overall survival between groups, as shown in Table 2. One POC animal had a hypoxic cardiac arrest during the initial intubation attempt despite pre-oxygenation from the POC.

3.4 | Primary outcome: PaO_2

There was a significant difference using mixed-model analysis among groups with regards to PaO_2 following reintubation and through the end of the critical care period (Figure 3, $p < 0.0001$) in favor of the

TABLE 1 Baseline characteristics, hemodynamic, and laboratory data.

Parameter	Portable oxygen concentrator, mean ± SD	Oxygen cylinder, mean ± SD	Control, mean ± SD	
N	9	9	9	*p*-Value
Demographic, weight (kg)	62.7 ± 3.2	35.9 ± 4.0	66.3 ± 3.0	0.1221
Hemodynamics				
End tidal CO_2 (mmHg)	42.2 ± 5.1	43.9 ± 1.3	43.7 ± 1.3	0.4811
Mean arterial pressure (mmHg)	80.2 ± 14.7	78.2 ± 14.7	84.9 ± 14.6	0.6178
Oxygen saturation (%)	94.8 ± 5.0	98.2 ± 2.3	95.4 ± 3.1	0.1314
Heart rate (beats/min)	79.7 ± 9.1	81.3 ± 18.0	82.1 ± 14.7	0.9346
PaO_2 (mmHg)	123 ± 11	131 ± 17	127 ± 9.3	0.3860
Laboratory				
Potassium (mEq/L)	3.7 ± 0.1	3.7 ± 0.2	3.8 ± 0.2	0.5963
Lactate (mmol/L)	1.5 ± 0.4	1.3 ± 0.4	1.4 ± 0.3	0.5192
HCO_3 (mEq/L)	26 ± 1.7	26 ± 1.2	26.6 ± 1.2	0.6423

Abbreviations: HCO_3, bicarbonate; PaO_2, partial pressure of oxygen; SD, standard deviation.

TABLE 2 Intubation and survival data.

	Portable oxygen concentrator, mean ± SD	Oxygen cylinder, mean ± SD	Control, mean ± SD	*p*-Value
Intubation first pass success	89% (8/9)	77% (7/9)	89% (8/9)	>0.9999
Average intubation attempts	1.2 ± 0.7	1.3 ± 0.7	1.1 ± 0.3	0.7517
Time to first intubation (s)	38 ± 15	40 ± 11	32 ± 8	0.3710
Overall survival	89% (8/9)	100% (9/9)	100% (9/9)	>0.9999

Abbreviation: SD, standard deviation.

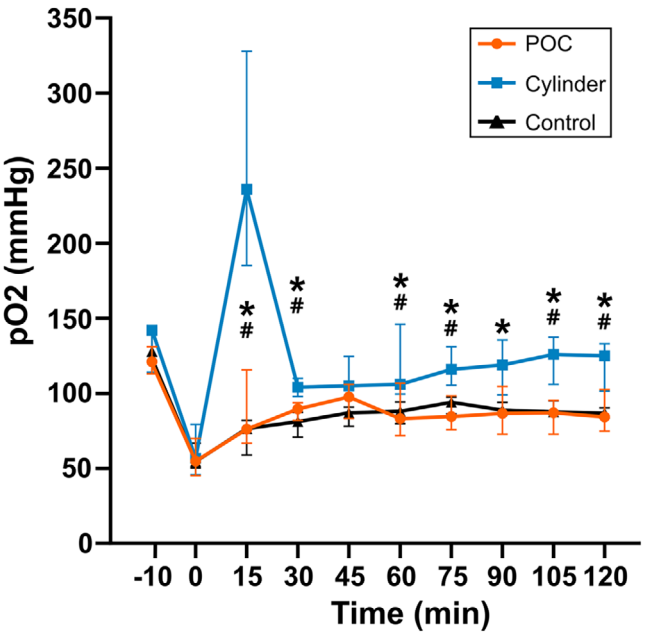

FIGURE 3 Partial pressure of oxygen (PaO_2) values. Samples were taken from femoral artery and the results are shown as median ± interquartile range. Overall *p*-value is <0.0001. Significant differences between control versus cylinder are denoted by symbol (*) and portable oxygen concentrator (POC) versus cylinder by symbol (#).

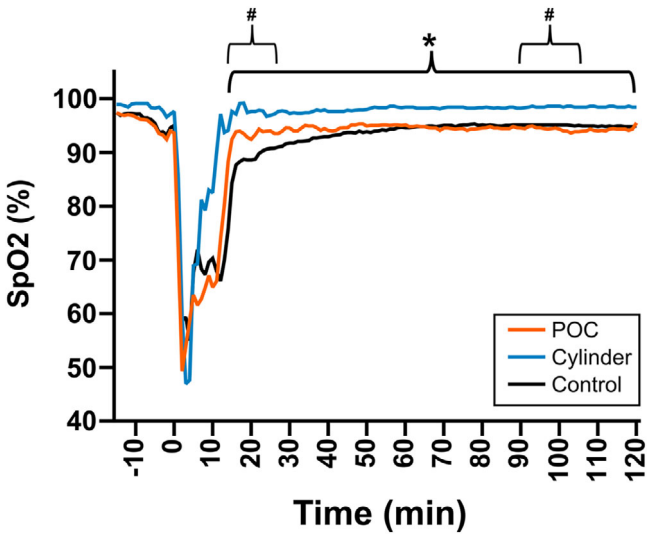

FIGURE 4 Peripheral oxygen saturation (SpO_2) values. Results represent means and error bars were removed for clarity. Overall *p*-value is 0.006. Significant differences ($p < 0.05$) between control versus cylinder are denoted by symbol (*) and portable oxygen concentrator (POC) versus cylinder by symbol (#).

oxygen cylinder. Calculated least square means (LS-means) over the experiment were 88.4 ± 14.0% for POC, 122.7 ± 46.2% for cylinder, and 88.9 ± 17.2% for control. Post hoc analysis showed statistically significant differences in PaO_2 between the oxygen cylinder and the POC ($p < 0.0001$), the oxygen cylinder and control ($p < 0.0001$), but not the POC and control ($p > 0.9999$). The PaO_2 immediately after re-intubation ($T = 15$ min) was markedly higher in the oxygen cylinder group. This difference decreased as the oxygen cylinder's flow volumes were titrated down and the animals were re-transfused.

3.5 | Secondary outcomes: SpO_2, rSO_2, device performance

There were significant differences in SpO_2 between groups throughout the entire experiment with LS-means for POC, cylinder, and control of 93.5 ± 4.0, 97.8 ± 1.8, and 92.6 ± 5.4% respectively (Figure 4, $p = 0.006$). Post hoc analysis revealed that there were significant differences between the oxygen cylinder and POC from re-intubation until $T = 20$ min, and significant differences between the cylinder and control through the remainder of the observation period. There were statistically significant differences in SpO_2 during periods of pre-oxygenation ($T = 10$–12 min), re-intubation ($T = 12$–14 min), and immediately after re-intubation ($T = 14$–20 min).

The rSO_2 data collected by NIRS shows a similar, albeit non-significant, trend, as shown in Figure 5. All three sensors showed a rapid decrease in tissue oxygenation across all groups after injury with slow, progressive improvements in all groups after pre-oxygenation, re-intubation, and re-transfusion during the critical care period with a non-significant trend showing the cylinder group returning to preinjury levels the earlier than the other groups.

3.6 | Device performance

All of the POCs' batteries were fully consumed prior to the end of the critical care period (43 ± 13 min of supplemental O_2 provided). All of

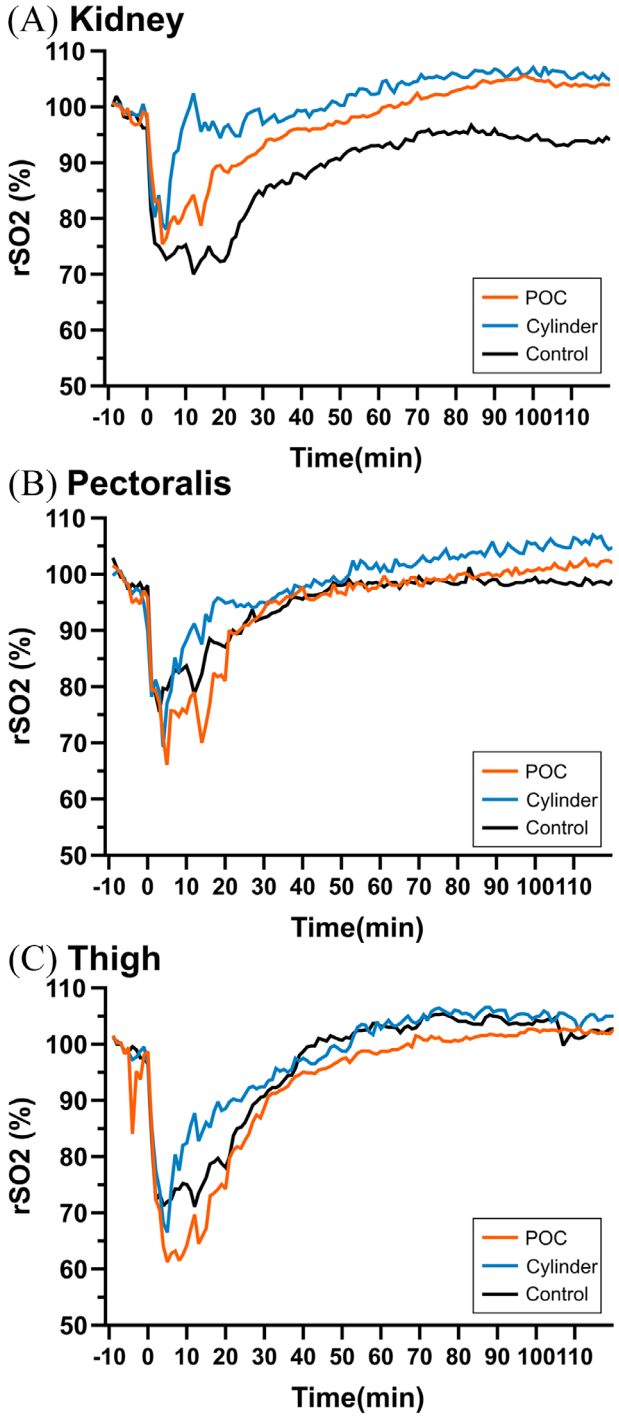

FIGURE 5 Near-infrared spectroscopy (NIRS) values from (A) kidney, (B) pectoralis, and (C) thigh. Results represent means and error bars were removed for clarity. POC, portable oxygen concentrator.

the M-15 oxygen cylinders had compressed oxygen remaining at the end of the critical care period (1094 ± 330 PSI remaining).

4 | LIMITATIONS

Applying these results to human patients in austere or combat settings requires an understanding of the experimental limitations of this study. Although swine provide a reliable model and are extensively used animal models during polytrauma research,[13] they have different pulmonary and airway structures than humans, which could impact experimental oxygenation. It is possible that SpO_2 and rSO_2 results would be different in humans as sensors are optimized for human skin. Second, the study was designed to follow military resuscitation protocols and empirically placed chest tubes on the side of injury for presumed pneumothorax given widespread evidence of pulmonary injury and rib fracture during model development. We cannot speculate on how the animals would have performed without chest tube intervention. Next, we tested the POC on only continuous mode as it is simple and practical to use with a low-flow ventilator set up. We do not believe that impractical, invasive ventilator modifications required to use the POC on pulse-dosed mode would have greatly improved oxygenation. To ensure animal analgesia during injury, animals were intubated and sedated during experimental preparation. Humans would not have received sedation, have been intubated, and subsequently extubated prior to an injury. While this was partially mitigated by the length of the simulated downtime, all animals required 2–3 min of bag-valve ventilation immediately after injury and extubation to prevent pre-randomization demise. However, the exact level of bag-valve support required in the first 3 min varied by animal. Due to the nature of the study, the research team was not blinded to the intervention and was required to titrate the oxygen source, which introduces possible bias. Lastly, although it was not statistically significant, the oxygen cylinder group trended toward higher baseline SpO_2 results. As randomization occurred well after pre-experimental oxygenation challenge and baseline data collection, this represents natural variation in the swine population but could impact subsequent experimental data.

5 | DISCUSSION

POCs have been suggested as a solution to oxygenation during military resuscitation and in austere, civilian environments. However, this study demonstrates significant limitations of ruggedized, man-portable POCs during simulated polytrauma intubation and resuscitation. There were no statistically significant differences in PaO_2 between the POC and control animals that received only room air. Although the POC group did have marginal statistically and clinically significant improvements in SpO_2 when compared to room air, the POC significantly underperformed compared to a high-pressure oxygen cylinder during pre-oxygenation, intubation, and immediately post-intubation.

Our study simulates the initial airway management of a patient that required intubation, chest tube placement, and whole blood transfusion. As seen by rapid declines in MAP and SpO_2, this represented a model of severe injury. The animals required bag-valve ventilation immediately after injury, due to combination of blunt chest injury, ongoing hemorrhage, and the ketamine sedation required to simulate the injury. Our study showed supplemental oxygen was required to overcome profound hypoxia during periods of life-threatening hypotension and to provide pre-oxygenation prior to intubation. Furthermore, across all groups, the oxygen required to overcome this

deficit progressively declined as the animal model was re-transfused whole blood. These trends were seen across PaO_2, SpO_2, and rSO_2. We preferentially selected PaO_2 as the primary outcome as it is a highly reliable indicator of oxygen delivery, despite only being drawn at fixed intervals. By contrast, SpO_2 and rSO_2 provided real-time changes in oxygenation, although less reliable in a swine model of polytrauma. We believe this is a limitation of the continuous volume the POC can provide. When severely injured, hypotensive, and requiring intubation, our data suggest that the 6 L of O_2 (3 L/min × 2 min) provided during preoxygenation, followed by the 3 L/min during the critical care period, was insufficient to overcome the underlying oxygen debt.

Many military medics preferentially perform cricothyroidotomies in combat and austere environments due to lack of medical equipment such as supplemental oxygen, need for immediate and definitive airway management, and lack of intravenous access. However, previous research has shown field cricothyroidotomies have a high failure rate in austere conditions.[14] Many medical providers, including military surgical teams, preferentially intubate when possible. Therefore, our study was designed to evaluate POCs in a near worst-case scenario: intubating a severely injured casualty with limited oxygen resources. The 3 L/min provided by the POC in continuous mode did not appear to sufficiently preoxygenate the animals prior to intubation and there was a noticeable lag in recovery of PaO_2 and SpO_2 after intubation, compared to the oxygen cylinder. Due to our rapid intubation times in a controlled laboratory environment, we anticipate that these findings would be exacerbated in real-world scenarios. Given the carrying capacity of a medic and the marginal benefits provided by a battery powered, man-portable POC, our data show that such POCs have limited utility when in austere or combat conditions. While the oxygen cylinder did result in superior oxygenation, it is a non-viable intervention in most military scenarios as cylinders risk explosive decompression if struck by a high-velocity projectile during combat.[6] Due to these risks, oxygen is often not available during initial care under fire and PFC periods of resuscitation. It was included as part of this study to provide reference to an intubation in a high-resource setting, such as urban EMS or at an emergency department.

We believe POCs continue to have a role in providing medical care in the low-resource environment. Integrating the POC on continuous mode into the low-flow set up of the ruggedized ventilator was rapid and easy to accomplish. At fixed locations, with access to electricity, it would be possible to combine the outputs of multiple POCs to improve oxygen flows. This greatly improves oxygen logistics for medical teams which may have unreliable logistics networks. Furthermore, as data from austere civilian and military assets have shown, POCs have been successfully utilized for non-emergent surgical procedures and treatment of medical pathologies, such as COVID-19. Medical providers should consider which commercially available POC is best for their deployed conditions. There are larger, less mobile POCs commonly used in high-resource settings (such as household treatment of chronic obstructive pulmonary disease) that provide flow rates up to 10 L/min.[3] However, the additional O_2 flow provided by these larger devices should be balanced against the mobility limitations of larger equipment.

In summary, we performed a translational research study to compare oxygenation from a man-portable POC, an M-15 oxygen cylinder, and a control group with no oxygen supplementation in a swine model of polytrauma. Our results showed that the POC underperformed the oxygen cylinder across a variety of oxygen parameters, including PaO_2 and SpO_2, and provided only marginal benefits compared to room air. Given the weight and limited duration of the ruggedized POC's battery, we believe that man-portable POCs have limited utility when hand-carried into austere and combat conditions. Medical assets with continuous electricity and fixed locations will continue to benefit from POC use, but the selection of the appropriate POC may vary by asset size and mission.

AUTHOR CONTRIBUTIONS

Conceptualization, *funding acquisition*, *methodology*, *investigation*, *resources*, *formal analysis*, *writing—original draft*, *writing—review and editing*: Craig Nowadly. *Methodology*, *investigation*, *resources*, *data curation*, *and writing—review and editing*: Nola Shepard. *Investigation and writing—review and editing*: Montane Silverman. *Methodology*, *investigation*, *resources*, *formal analysis*, *writing—original draft*, *and writing—review and editing*: Jason Rall.

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CONFLICT OF INTEREST STATEMENT

The views expressed are those of the authors and do not reflect the official views or policy of the Department of Defense or its Components. The experiments reported herein were conducted according to the principles set forth in the National Research Council's Guide for the Care and Use of Laboratory Animals (8th ed.), and the Animal Welfare Act of 1966 as amended. The views of the manufacturers are not necessarily the official views of, or endorsed by, the U.S. Government, the Department of Defense, or the Department of the Air Force. No Federal endorsement of the manufacturer is intended.

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