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The performance of Dräger Oxylog ventilators at simulated altitude

J. G. FLYNN*, B. SINGH†

Institute of Aviation Medicine, Royal Australian Air Force Base, Edinburgh, South Australia, Australia

SUMMARY

Ventilated patients frequently require transport by air in a hypobaric environment. Previous studies have demonstrated significant changes in the performance of ventilators with changes in cabin pressure (altitude) but no studies have been published on the function of modern ventilators at altitude. This experiment set out to evaluate ventilatory parameters (tidal volume and respiratory rate) of three commonly used transport ventilators (the Dräger Oxylog 1000, 2000 and 3000) in a simulated hypobaric environment. Ventilators were assessed using either air-mix (60% oxygen) or 100% oxygen and tested against models simulating a normal lung, a low compliance (Acute Respiratory Distress Syndrome) lung and a high-resistance (asthma) lung. Ventilators were tested at a range of simulated altitudes between sea level and 3048 m. Over this range, tidal volume delivered by the Oxylog 1000 increased by 68% and respiratory rate decreased by 28%. Tidal volume delivered by the Oxylog 2000 ventilator increased by 29% over the same range of altitudes but there was no significant change in respiratory rate. Tidal volume and respiratory rate remained constant with the Oxylog 3000 over the same range of altitudes. Changes were consistent with each ventilator regardless of oxygen content or lung model. It is important that clinicians involved in critical care transport in a hypobaric environment are aware that individual ventilators perform differently at altitude and that they are aware of the characteristics of the particular ventilator that they are using.

Key Words: ventilators, aeromedical, altitude, hypobaric

Aeromedical retrieval organisations such as the Royal Flying Doctor Service of Australia (RFDS) transport a large number of ventilated patients by air every year (340 patients in 2006 in Western Australia alone). Most of these patients are exposed to a hypobaric environment, as all rotary-wing aircraft used for aeromedical transport in Australia are unpressurised and cabin altitude of fixed-wing aircraft usually lies in the range of 2000 to 3000 m, even with pressurisation. Most pressurised aircraft can opt to increase their cabin pressure (thus reducing the level of hypobaria to which patients are exposed) by either changing the cabin pressurisation settings, or by flying at lower altitudes. Both these options are exercised only if unavoidable, due to penalty in terms of reduction in range, endurance, fuel economy and increased air turbulence at lower altitudes.

In 2006 the Western Australian section of the RFDS Western Operations purchased a number of Oxylog 3000 ventilators (Dräger Medical, Lübeck, Germany) to supplement its stock of Oxylog 1000 ventilators. It was noted that the two ventilators seemed to perform differently at altitude.

A literature search of Medline conducted in September 2006 using the MeSH database items “Ventilator”, “Ventilation”, “Altitude” and “Hypobaric” revealed a number of studies that have demonstrated that ventilator function can change significantly at different altitudes[1-5]. Most recently, in 1996 Roeggla et al[4,5] demonstrated falls in respiratory rate and rises in tidal volume and minute volume in the hypobaric environment with the Dräger Oxylog (a model now known as the Oxylog Basic) and the AmbuMatic ventilator (Ambu A/S, Ballerup, Germany) in 1995 to 1996. These studies confirmed the findings of Thomas and Brimacombe[3] using the Dräger Oxylog Basic. A review article by Kashani and Farmer[6] on the support of severe respiratory failure during transportation included a discussion on the effects of altitude on the Univent models 750 and 754 portable ventilators (Impact Instumentation Inc, Caldwell, NJ, USA). They described a recalibration process using the Univent model 750 ventilator at altitude that requires the patient to be disconnected from the ventilator for 60 seconds. They also stated

*M.B., B.S., F.R.A.C.G.P., F.A.C.R.R.M., Dip.R.A.C.O.G., Dip.I.M.C.R.C.S.Ed., Senior Registrar, Department of Emergency Medicine, Princess Margaret Hospital for Children, Subiaco, Western Australia.

†Dip.Av.Med., M.D., F.A.e.M.S, Associate Professor and Head of Research.

Address for reprints: Dr James Flynn, Department of Emergency Medicine, Princess Margaret Hospital for Children, Roberts Rd, Subiaco, WA 6008.

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that the Univent Eagle model 754 ventilator avoids this problem by the inclusion of an internal barometer that recalibrates the delivery of gas with changing altitude. The source of their information on these ventilatory functions was based on "personal communication" and on "data testing by the Aeromedical Research Group at the Armstrong Laboratories (unpublished information)". Neither of these ventilators is in common use in Australia. Zanetta et al[7] tested the function of a number of portable ventilators (including the Oxylog 1000 and 2000) in 2002 but did not measure response to variations in altitude (pressure) in their experiment.

There was thus no published original research data on the performance of ventilators at altitude since 1996. In particular, there was no published data on the performance at altitude of the Oxylog 1000 or Oxylog 3000 ventilators nor was there data on the Oxylog 2000 ventilator, the ventilator currently used by the Royal Australian Air Force.

The primary objective of this study was to document the changes, if any, in tidal volume and respiratory rate with simulated increasing altitude and with varied lung mechanics with three transport ventilators currently used in the Australian aeromedical environment.

MATERIALS AND METHODS

The experiment was performed in the hypobaric chamber at the Institute of Aviation Medicine, Royal Australian Air Force Base, Edinburgh, South Australia. Three portable ventilators, the Oxylog 1000, Oxylog 2000 and Oxylog 3000, were tested. One ventilator of each type was assessed – the Oxylog 1000 and 2000 units were randomly chosen from retrieval service stock (RFDS Western Operations and Royal Adelaide Hospital Mediflight respectively) while the Oxylog 3000 was a demonstration model supplied by Dräger. All ventilators assessed had current Dräger service certification.

Each ventilator was connected to a Demonstration Thorax TE020790 test lung (Dräger Medical, Lübeck, Germany). Tidal volume was set at 500 ml and respiratory rate at 15 breaths/minute and the settings were left unchanged during the course of the experiment. Delivered tidal volume was measured through a size 1 pneumotach using a Digital Pneumotach Vertek Series spirometer (Hewlett Packard, Palo Alto, CA, USA). The spirometer was checked at each altitude using a 3 l calibration syringe (Welch Allyn, Skaneateles Falls, NY, USA) and was found to be unaffected by changes in simulated altitude. Respiratory rate was calculated from a printout of the respiratory waveform on a portable monitor (Dash 3000, GE Healthcare, Chalfont St Giles, Bucks, UK).

Pressure settings in the chamber were adjusted to simulate a number of altitudes between 'sea level' (17 m above sea level, the true height of the chamber) and 3048 m (10,000 ft, the maximum permissible cruising altitude for unpressurised aircraft)[8].

Each ventilator was assessed using an inspired oxygen content of 100% against three lung models – a normal lung (compliance 48 ml/cmH_2O, resistance 10 cmH_2O/l/sec, 5 cm of positive end expiratory pressure (PEEP)), an Acute Respiratory Distress Syndrome (ARDS) model (compliance 29 ml/cmH_2O, resistance 10 cmH_2O/l/sec, 5 cm of PEEP) and an asthma/tube obstruction airway pattern (compliance 48 ml/cmH_2O, resistance 50 cmH_2O/l/sec, no PEEP). In addition, the normal lung model was evaluated with the inspired oxygen content set to 60% ('Airmix' on Oxylog 1000 and 2000).

Data was entered into a spreadsheet (Microsoft® Office Excel 2003) and analysed visually for trends.

The project was reviewed by the Royal Australian Air Force Health and Human Performance Research Committee. It was agreed that ethical approval was not required as the exposure of the human operator was limited to a simulated altitude of 3048 m, which is no more than experienced in a commercial flight.

RESULTS

The changes measured with differing simulated altitudes, different inspired oxygen contents and different lung models are shown in Table 1.

Tidal volume delivered by the Oxylog 1000 ventilator increased by an average of 68% over the altitude range 17 to 3048 m for all four lung models. Respiratory rate fell consistently, with an average decrease of 28% over the range tested. The average increase in minute ventilation (tidal volume × respiratory rate) was 11% at 1829 m (a common cruising cabin altitude for aeromedical aircraft) and 21% at 3048 m. Changes with altitude appeared to be consistent regardless of the oxygen content or lung model used.

Tidal volume delivered by the Oxylog 2000 ventilator increased by an average of 29% over the altitude range 17 to 3048 m for all four lung models. Respiratory rate for the Oxylog 2000 remained constant over the same altitude range. The average increase in minute ventilation was 15% at 1829 m and 29% at 3048 m. Again, changes seemed consistent regardless of the oxygen content or lung model used.

TABLE 1
Effect of change in simulated altitude on tidal volume and respiratory rate

	Tidal volume (ml)				Respiratory rate (breaths/minute)			
	Altitude				Altitude			
	17 m	1829 m	3408 m	% change*	17 m	1829 m	3408 m	% change*
Oxylog 1000								
0.6 NC NR	482	645	787	63%	14.9	12.3	10.8	-28%
1.0 NC NR	505	688	867	71%	15.2	12.5	10.9	-28%
1.0 LC NR	503	673	843	68%	15.2	12.6	10.9	-28%
1.0 NC HR	497	671	843	70%	15.2	12.6	10.9	-28%
Oyxlog 2000								
0.6 NC NR	486	566	639	31%	15.2	15.2	15.2	0%
1.0 NC NR	475	542	604	27%	15.2	15.2	15.2	0%
1.0 LC NR	473	544	606	28%	15.2	15.2	15.2	0%
1.0 NC HR	473	544	604	28%	15.2	15.2	15.2	0%
Oxylog 3000								
0.6 NC NR	503	508	508	1%	14.9	14.9	14.9	0%
1.0 NC NR	525	531	533	2%	14.9	14.9	14.9	0%
1.0 LC NR	529	527	527	0%	14.9	14.9	14.9	0%
1.0 NC HR	533	535	535	0%	14.9	14.9	14.9	0%

0.6 = 60% O_2, 1.0 = 100% O_2. NC = normal compliance, NR = normal resistance, LC = low compliance, HR = high resistance. * change in tidal volume or respiratory rate from 17 m to 3048 m.

Tidal volume and respiratory rate remained unchanged with the Oxylog 3000 up to 3048 m. Consistency was maintained regardless of the oxygen content or lung model used.

DISCUSSION

This study demonstrates that individual ventilators perform differently when exposed to simulated altitude. The difference in performance of the three ventilators can be explained by their different design characteristics. The Oxylog 1000 is a time-cycled, volume-constant ventilator with pneumatic logic controls. It has the capacity to deliver 100% oxygen or an 'air mix' of approximately 60% oxygen through a venturi injector. It has no electronic parts. Respiratory rate is varied by rotating a needle valve which controls the flow of gas into a capacitance chamber. Switching between inspiratory and expiratory mode is triggered by a change in pressure in the capacitance chamber. The mass of gas required to trigger this change is constant but in the hypobaric environment a larger volume of gas is required. As the volume flow into the chamber is constant and the inspiratory to expiratory ratio is fixed, the longer inspiratory time leads to a fall in respiratory rate. Tidal volume in the Oxylog 1000 is also controlled by a simple mechanical needle valve. The mass flow across the valve decreases with falling ambient pressures but the expansion of gas due to Boyle's law means that a larger tidal volume is delivered at the same ventilator setting at higher simulated altitudes. Mechanically the Oxylog 1000 is similar to the Oxylog Basic. The changes measured in this experiment correlate closely with those documented by Thomas in 1994[3] and Roeggla et al[4] using the Oxylog Basic.

The Oxylog 2000 is a time-cycled, volume-constant ventilator with electronic logic controls. Respiratory rate is controlled electromechanically via a micro-solenoid valve. As it is controlled electronically rather than being pressure-dependent, the rate delivered remains constant independent of ambient altitude. Tidal volume in the Oxylog 2000 is, like the Oxylog 1000, controlled by a mechanical needle valve that delivers gas that expands at lower simulated altitude, delivering larger tidal volumes.

The Oxylog 3000 is a time-cycled, volume-constant ventilator with electronic logic controls. Like the Oxylog 2000, the Oxylog 3000 uses a micro-solenoid valve to electrically control the respiratory rate, which maintains a constant rate regardless of ambient pressure. It also incorporates absolute pressure sensors in its design that measure the ambient pressure at two-minute intervals and corrects the volume of gas delivered accordingly (Dräger Australia, personal correspondence).

There are a few limitations to this study. Only one set of readings was obtained for each ventilator at altitude with each oxygen setting and each lung model. To keep the number of hypobaric chamber runs within manageable limits, the investigators had to choose between assessing multiple models and settings or choosing one model and repeating the measurements on a number of chamber runs. It was thought that more clinical value would be obtained by varying as many parameters as possible. It would be useful to repeat each set of data a number of times in order to statistically verify the changes that were seen. However, visual analysis of the graphed data demonstrates consistent patterns that appear unlikely to be due to chance alone. Second, only one ventilator of each type was assessed, and it cannot necessarily be assumed that every ventilator will perform in exactly the same manner as the models that were tested. However, the performance of the ventilators is design-based and is not expected to vary across the same model.

It is important to emphasise that no attempt was made to compare other functions of portable ventilators such as size, ease of use, power source, ventilatory functions or cost.

The potential clinical implications resulting from the changes documented in this study relate to change in delivered tidal volume and minute ventilation. There is a body of evidence in the literature that suggests that high tidal volumes are harmful in patients with ARDS[9]. Some authors have postulated that patients without lung injury would also be better off if managed with lower tidal volumes[10]. We have demonstrated that patients in the aeromedical environment could be exposed to tidal volume increases of as much as 68% at higher altitudes at lower cabin pressures. It is reasonable to assume that, if left unchecked, the higher tidal volumes at altitude could adversely affect patient outcomes, especially in patients with the ARDS. In addition to the changes in tidal volume, a rise in minute ventilation at altitude (up to 29%) will lead to hypocapnia, which may cause a shift of the oxyhaemoglobin dissociation curve to the left, hypokalaemia and decreased cerebral blood flow[11].

It is important that staff involved in aeromedical transfers are aware that some ventilators perform differently in the hypobaric environment. Close monitoring and adjustment of ventilatory parameters in patients ventilated with either the Oxylog 1000 or Oxylog 2000 is important to minimise the risk of ventilator-associated lung injury.

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