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ASSESSMENT OF THE CAMPBELL "D-MODE" VENTILATOR UNDER HYPERBARIC CONDITIONS

Marcus Skinner

Key Words

Equipment, hyperbaric research, ventilators.

Introduction

The Royal Hobart Hospital commissioned a new Hyperbaric Chamber in February 1993. Since that time a review of in-chamber equipment has been undertaken. A Penlon 200 is used in this facility and a backup ventilator was needed. An assessment of currently available ventilators for use in the chamber was carried out.[1] A Campbell D Mode ventilator was made available for assessment by ULCO Engineering. No performance reports on the function of Campbell ventilators under hyperbaric conditions have been identified in the literature.

Methods

The Campbell D-Mode Portable ventilator is an Australian made pneumatic, time cycled, volume and rate preset, constant flow generation ventilator developed by ULCO Engineering. Its driving gas supply is medical air or oxygen supplied at 60 psi (415 kPa) gauge of which it consumes 1 l/min in addition to the minute volume. The ventilator was assessed under normal and hyperbaric conditions. Its ability to deliver a preset volume or rate was assessed at three pressures.

At 1 bar it delivers tidal volumes from 50 ml to 2,000 ml with inspiratory times of 0.5-2.0 seconds and expiratory times ranging from 1.0-6.0 seconds. Timing is controlled by graduated scales. Inspiratory time for the ventilator, on each of its graduations, was measured using a digital stopwatch (average of five readings) at each pressure.

The ventilator was attached to a Siemens test lung (compliance rated at 50 ml/cm H_2O/l) to simulate a patient's lung. The manufacturer states that the specific compliance of normal lung is in the region of 60-70 ml/cm H_2O/l.

A Wright's respirometer, calibrated using a 2 litre Rudolph gas calibration syringe, was used to measure tidal volumes at 1 bar (surface), 2.4 bar (14 m) and 2.8 bar (18 m). Calibration at 1 bar and 2.8 bar showed that the Wright's Spirometer over-read the tidal volume by an average of 6% at low volumes and by 3% at high volumes. The recordings have been adjusted to reflect this error.

The "D" Mode ventilator flow control was set at 1.0, 0.75 and 0.5 and the tidal volume measured for each inspiratory time setting (0.5, 0.75, 1.0, 1.25, 1.5 and 2.0 seconds). Expiratory time was left at the 2.0 seconds setting for convenience and to allow for a greater than 1:2 inspiratory to expiratory (I/E) ratio. The setting of the expiratory time does not affect the inspiratory time setting. The tidal volume at each inspiratory time setting was measured three times and averaged. These measurements were repeated at each pressure.

From the data obtained a series of graphs indicating the tidal volume for given ventilator settings and tidal volume at maximal flow for three depths was constructed. A further graph depicting the minute volume at maximal flow was constructed for each depth.

Results

The results of the study are shown in Figures 1-5. The narrow variation within each group of readings reflects the consistent performance of the ventilator. Figures 1-3 present the tidal volumes achieved for different flow settings over the ventilator's range of inspiratory times at 1 bar, 2.4 bar and 2.8 bar. Figure 4 presents the tidal volumes achieved at these three depths at maximal flow. Figure 5 presents the minute volumes achieved at these three depths for maximal flow.

It is clear that the performance of the Campbell D Mode ventilator decreases with pressure as at 1 bar it delivers more than twice the volumes available at 2.4 bar and approximately three times the volumes available at 2.8 bar. To achieve a minute volume of 10 l at 2.4 bar, flow must be set to maximum and inspiratory time to at least 1.25 seconds with an expiratory time of two seconds. At 2.8 bar a minute volume of 10 l cannot be achieved.

Discussion

As would be expected for a pneumatic, time cycled, constant flow ventilator the performance of the Campbell D Mode ventilator decreased significantly as the chamber

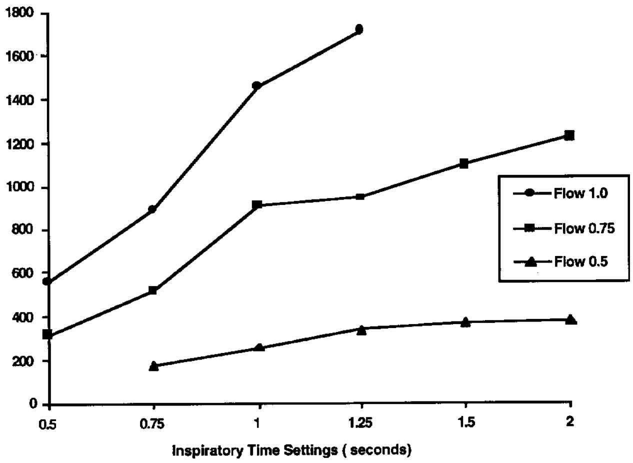

Figure 1. Tidal volumes at 1 bar for each inspiratory time setting (0.5-2 seconds), with the expiratory time constant at 2 seconds, for three flow settings (0.5, 0.75 and 1).

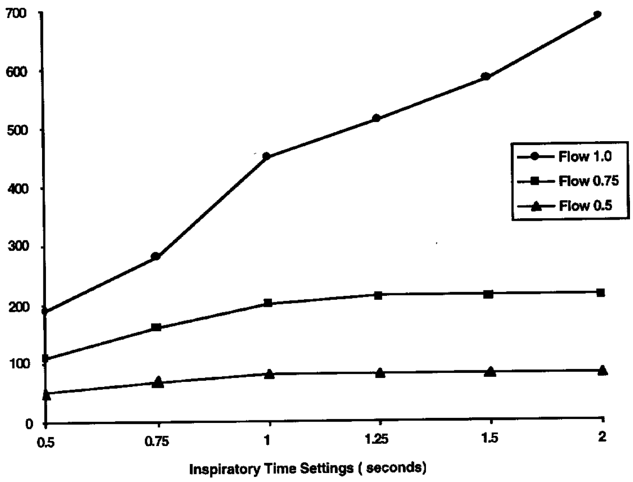

Figure 2. Tidal volumes at 2.4 bar for each inspiratory time setting (0.5-2 seconds), with the expiratory time constant at 2 seconds, for three flow settings (0.5, 0.75 and 1).

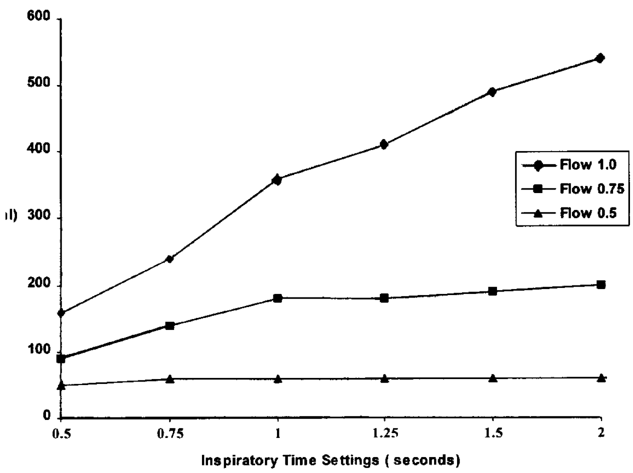

Figure 3. Tidal volumes at 2.8 bar for each inspiratory time setting (0.5-2 seconds), with the expiratory time constant at 2 seconds, for three flow settings (0.5, 0.75 and 1).

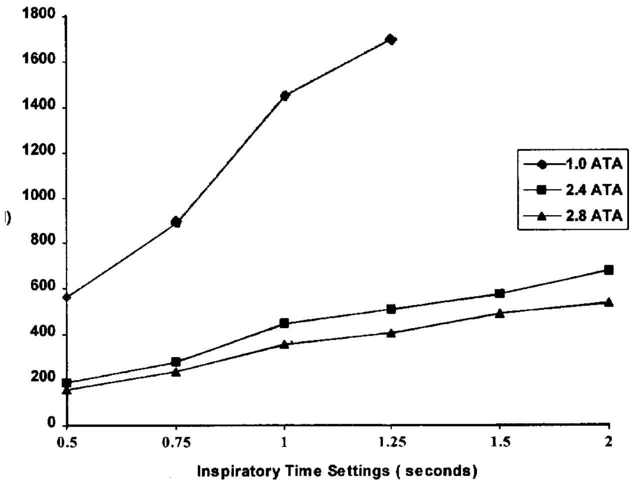

Figure 4. Tidal volumes for each inspiratory time setting (0.5-2 seconds), with the expiratory time constant at 2 seconds, for the maximum flow setting (1) at 1. 2.4 and 2.8 bar.

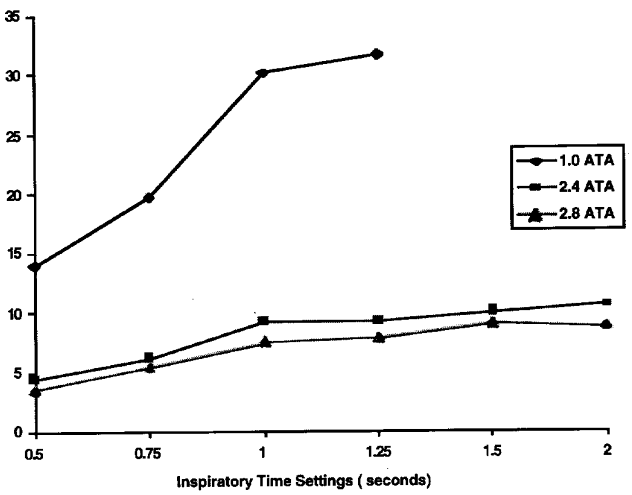

Figure 5. Minute volumes for each inspiratory time setting (0.5-2 seconds), with the expiratory time constant at 2 seconds, for the maximum flow setting (1) at 1. 2.4 and 2.8 bar.

pressure increased. Such changes have also been documented for the Oxford Penlon 200 ventilator.[2] The Campbell D Mode does not approach the extended range or the reported performance of the Pneupac HC hyperbaric ventilator.[3]

It is apparent that the Campbell D Mode ventilator is incapable of providing clinically acceptable tidal volumes to the average adult patient at pressures beyond 2.8 bar (18 m). At the Royal Hobart Hospital facility patients are routinely treated at 14 m (2.4 bar) and 18 m (2.8 bar). At the maximal flow setting (1.0) and with the inspiratory time setting of 1.0 second and an expiratory setting of 2 seconds (I/E Ratio 1:2) the tidal volume was 460 ml at 2.4 bar and 380 ml at 2.8 bar. With the inspiratory time increased to 1.5 seconds these values increased to 590 ml and 500 ml respectively. In order to maintain clinically acceptable minute volumes in patients the tidal volumes must be monitored and the rate adjusted accordingly. This requirement has been mentioned in other studies in which the minute ventilation was measured by a suitably calibrated spirometer.[3-6]

In clinical practice the delivered tidal volume may alter with changing lung compliance, whereas in this study the test lung compliance remained unaltered. It is accepted that patients' lung compliance may alter, particularly in the critically ill patient. In previous studies the clinical significance of changes in patients lung compliance at depth and its effects on positive pressure ventilatory tidal volumes was not investigated.

Use of the Campbell D Mode ventilator on patients in our chamber suggests that the changes in patient lung compliance at pressures of 2.8 bar are of minimal significance. This ventilator was not designed specifically for hyperbaric use. When considering the aspects required of the ideal hyperbaric ventilator[1] the Campbell D Mode is robust, simple to operate and easy to maintain. The controls are clear and simple to use with well defined graduations. It has visual and auditory disconnect alarms and may operate on air or oxygen. The ventilator driving gas (oxygen) pressure remains constant at depth and has no significant influence on the delivery of an adequate tidal volume.

The inspiratory and expiratory times of pneumatically time cycled ventilators, including the Campbell D Mode, shorten with increasing ambient pressure.

The Campbell D Mode ventilator has been found to be an acceptable alternative to the Penlon 200 that has been in use in our chamber. It has the same disadvantages as the Penlon but has the major advantage of being capable of being preset by dialling up set graduations on the machine. This has been found helpful for Intensive Care ventilator trained staff who use the ventilator only occasionally. Spirometry is used in the clinical setting and adaptation for end tidal CO_2 monitoring is being undertaken.

Conclusions

The desirable features of the ideal hyperbaric ventilator have been proposed elsewhere.[1] The Campbell 'D' Mode ventilator meets some of these requirements. It is robust and simple to operate and maintain. The driving gas can be air or oxygen. The ventilator's controls allow for known values to be set. A warning system for disconnection or reduced inspiratory pressure is part of the ventilator.

The Campbell D Mode ventilator provides an alternative to the Penlon 200 for the average adult patient. However it does not achieve the desired maximal inspiratory flow rate of 80 l/min at depth (2.8 bar) where its maximum flow is only 35 l/min. At 2.8 bar tidal volumes above 600 ml cannot be achieved. It would be unable to provide clinically acceptable tidal volumes in some clinical circumstances (e.g. the morbidly obese) and further studies are needed to identify its clinical limits.

The PEEP function has not been evaluated. Controlled ventilation in the hyperbaric chamber presents a variety of challenges and risks that require further evaluation.

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THE WORLD AS IT IS

1997 ANNUAL MEETING OF THE AUSTRALIAN HYPERBARIC TECHNICIANS AND NURSES ASSOCIATION

Eric P Kindwall

Key Words
Hyperbaric facilities, meeting.

The Coogee Beach Hotel was the venue for the 5th Annual Scientific Meeting of the Australian Hyperbaric Technicians and Nurses Association (HTNA) 28-30 August 1997. Coogee Beach is a pleasant seaside suburb of Sydney, which in August was welcoming the beginning of spring "down under". There were well over 100 participants from the nine hyperbaric facilities in Australia, all hospital-based units with multiplace chambers. More than 30 papers were submitted to the meeting; slightly over half of them dealt with clinical hyperbaric medicine and the remainder with diving-related subjects. Laura Josefson, RN, President of the BNA, and I were guests of the HTNA and were given ample time to speak on the program.

The clinical hyperbaric subjects were broad and varied. They included impaired neutrophil adhesion in patients with diabetes, the problem of claustrophobia in the chamber, injury mechanisms in carbon monoxide poisoning, psychiatric profiles of patients with carbon monoxide poisoning, a survey of middle ear barotrauma in unconscious patients, an update on the results of hyperbaric incident monitoring (the HIMS Study) and the use of tympanostomy tubes.

The divers dealt with the treatment of decompression sickness, DCS at very shallow depths, technical diving subjects and the practicality and utility of square hyperbaric chambers.

We were met at the airport by Dr Ian Unsworth, literally the founder of HBO therapy in Australia, who turned us over to the capable hands of John Kershler and Barrie Gibbons of the Prince of Wales Hospital HBO unit, who had made all our travel arrangements.

The highlight of the trip for me and my family was a grand tour of the hyperbaric facilities in Australia, starting in Sydney with the Prince of Wales Hospital and HMAS PENGUIN, the Royal Australian Navy Diving Training Facility. Our travels then took us to the Royal Hobart Hospital in Hobart, Tasmania; the Alfred Hospital in