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FUNCTIONAL CHARACTERISTICS OF THE WRIGHT RESPIROMETER AND THE DRÄGER VOLUMETER UNDER HYPERBARIC CONDITIONS

John Whittle, Christopher S Butler and Ray Muller

Summary

An accurate and reproducible method for measuring minute volume under hyperbaric conditions is desirable for the safe conduct of assisted ventilation in the hyperbaric chamber. The Wright respirometer and Dräger 3000 volumeter were compared under normobaric and hyperbaric conditions (1, 2 and 3 bar or 101, 202, 303 kPa) to determine their precision and accuracy at physiologically relevant flow rates.

Although both devices demonstrated a high degree of precision, the accuracy of the Wright respirometer varied with both gas-flow rate and pressure. In contrast the accuracy of the Dräger 3000 volumeter was dependent on flow rate but independent of pressure. Both instruments are suitable for hyperbaric use so long as their limitations are understood.

Key Words
Equipment, hyperbaric research, treatment.

Introduction

Standard testing of commonly used volumeters under normobaric conditions has demonstrated an accuracy approaching +/- 5%.[1,2] Some published data exists on the functioning of the Wright respirometer under hyperbaric conditions, indicating over-reading by up to 18%.[3,4]

The high partial pressure of oxygen in the hyperbaric chamber imposes safety limitations on equipment such that devices requiring mains electrical power, heated wires or using touch button controls are unsuitable for use in the chamber. This excludes the majority of commonly used flow and volume meters leaving only mechanical meters (e.g. Wright respirometer and the Dräger volumeter) suitable for use. Sidestream end tidal CO_2 measurement, outside the chamber, may in future prove a useful alternative.[5]

Increases in gas density lead to reduced performance of ventilators, particularly if fluid logic controlled.[6] The reduction in the delivered tidal volume of set volume under hyperbaric conditions can lead to hypercarbia. As the Wright respirometer has been noted to over-read under hyperbaric conditions, this error is potentially compounded. The monitoring of ventilation with volumeters must therefore be conducted with an understanding of their limitations.

The Wright respirometer contains a light mica vane which rotates within a small cylinder (Fig 1). The wall of the cylinder is perforated with a number of tangential slits so that the air stream causes the vane to rotate. The rotation of the vane activates a gear chain which in turn drives the pointer around the dial. Calibration is performed using a sine wave pump to adjust the relationship between the number of rotations of the vane and the volume of gas which has passed through the meter.[7] This system has an inherent inertia so that the meter tends to over-read at high tidal volumes and flow rates. The instrument is suitable for use in conditions of high relative humidity (>60%) and temperatures up to 50° C.[1]

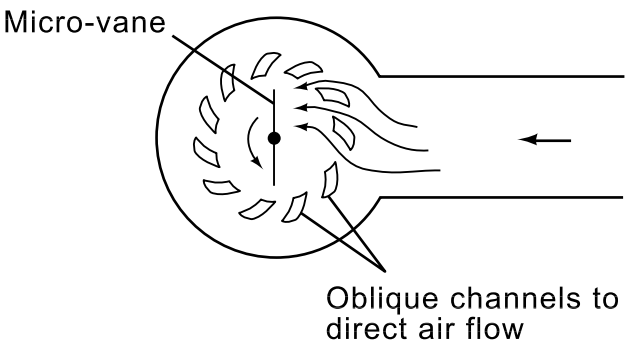

Figure 1. Wright Respirometer in cross-section (reprinted, with permission, from Sykes, Vickers and Hull[7]).

The Dräger range of volumeters register volume using two light interlocking dumb-bell-shaped rotors (Fig 2), which are set in motion by the passage of moving air at a speed dependent on the flow rate.[2] This movement is transferred to a pointer by means of a gear mechanism.

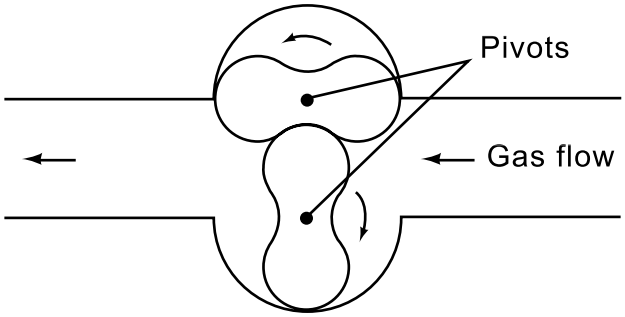

Figure 2. Dräger Volumeter in cross-section (reprinted, with permission, from Sykes, Vickers and Hull[7]).

The aim of this study was to assess and compare the accuracy and precision of the Wright respirometer and the Dräger volumeter, over a range of gas flows and chamber pressures used clinically, in order to determine the most suitable and reliable instrument for hyperbaric conditions.

Materials and methods

The Dräger Volumeter 3000 Adult and the Haloscale Wright respirometer were tested in the hyperbaric chamber against a standard calibrated one-litre syringe. The meters were tested at 1 (sea level), 2 and 3 bar and at flow rates of 20 and 50 l/min. To achieve reproducible flow rates over a series of measurements, the driving force for the syringe was provided by a rubber bicycle inner-tube. Outflow resistance to achieve the required flow rates from the calibrated syringe was achieved using an adjustable clamp applied to the outflow tubing. Mean flow rates were determined from these results. To demonstrate the reproducibility of the system at 1 bar a Vitalograph was employed to measure the output (Fig 3). During testing at 1 bar the volumeters were also tested with the Wright respirometer next to the pump. There were no noticeable differences in these readings from those obtained with the configuration used at higher pressures.

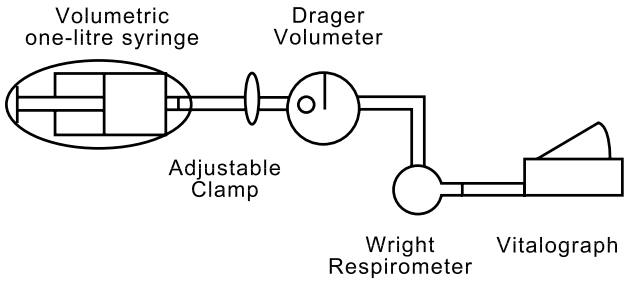

Figure 3. The configuration of the volumeter testing equipment at 1 bar. **Note.** Reversing the position of the volumeters did not alter their readings.

Due to the increased resistance to flow under hyperbaric conditions, the settings of the adjustable resistor had to be altered once the test pressure was reached. A stop watch was employed in the chamber to calculate flow rates because the Vitalograph was electrically powered.

Twenty readings from each meter at 20 l/min and at 50 l/min at each pressure (1, 2 and 3 bar) were performed to assess the meters' accuracy and precision. Throughout the study, chamber temperature was held at 25+/-2 C° and relative humidity was held at 85+/-5%. The composition of the chamber gas (air) did not alter and the hyperbaric chamber was located at sea-level.

Results

Table 1 (page 14) shows the Accuracy and Precision of all tests. Accuracy was calculated as the mean percentage difference from one litre as measured by the standard volumetric syringe. Precision was calculated as the mean percentage difference from the mean measured volume. In order to increase comparability across the test settings, the latter percentages were expressed as a proportion of the known volume (i.e. one litre) as opposed to a percentage of the measured means.

Discussion

The accuracy of the Wright respirometer was affected more by flow rate than chamber pressure. The two effects were additive so that at 3 bar and 50 l/min the meter readings were about 10% above the delivered volume. The precision of the meter was high with <1% mean difference from the mean measurement for all measurement conditions.

The precision of this instrument allows a correction to be made for flow rate and chamber pressure. However this correction factor is not linear and requires testing to be performed against a standard calibration syringe as described above. A solution to this problem is to have a number of meters each calibrated to a particular flow rate and chamber pressure.

In contrast, the performance of the Dräger 3000 volumeter was not greatly affected by altering chamber pressure. The meter was consistently inaccurate, over-reading by 8% at the lower flow rate of 20 l/min and by 14% at 50 l/min. Accuracy can be improved by recalibration. The importance of this finding is that a tidal volume

TABLE 1

MEAN AND MEDIAN READINGS WITH PRECISION AND ACCURACY CALCULATIONS

Meter	Chamber pressure	Flow rate	Mean reading [litres]	Median reading [litres]	Precision [percent]	Accuracy [percent]
Wright	1 bar	20l/min.	0.96	0.96	0.3	3.9
		50l/min.	1.03	1.03	0.5	3.2
	2 bar	20l/min.	1.03	1.03	0.5	2.5
		50l/min.	1.07	1.07	0.4	7.2
	3 bar	20l/min.	1.04	1.04	0.4	3.8
		50l/min.	1.10	1.10	0.3	10.1
Dräger	1 bar	20l/min.	1.08	1.08	0.4	7.9
		50l/min.	1.14	1.14	0.5	14.2
	2 bar	20l/min.	1.08	1.08	0.4	8.25
		50l/min.	1.13	1.13	0.5	13.5
	3 bar	20l/min.	1.09	1.09	0.4	8.7
		50l/min.	1.13	1.13	0.4	13.1

Precision is calculated as the mean percentage difference from the mean whilst accuracy is taken as the mean percentage difference from 1.

measured by the Dräger 3000 volumeter in a ventilated patient at 1 bar is the same volume at 2 and 3 bar. This allows monitoring of ventilation parameters to continue with confidence under hyperbaric conditions .

This study has demonstrated the contrasting performance characteristics of two readily available mechanical volumeters. The accuracy of both meters is affected by altering flow rate. However whilst the Wright respirometer becomes progressively less accurate with increasing pressure, the Dräger 3000 volumeter's performance is relatively independent of pressure. As such, we could recommend the Dräger 3000 volumeter for measuring tidal and minute volume in the ventilated patient under hyperbaric conditions. The proviso is that one must remember that the minute volume shown on the Dräger is higher than that delivered at all pressures. The Wright respirometer is also suitable if calibrated specifically for a set chamber pressure.

References

1 Medishield Respirometer Models RM121 and RM311 Operational Specifications

2 Dräger Volumeters 3000,2000K Technical Data; June 1981

3 Gibson AJ, Davis FM and Wilkinson AR. Assessment of the Pneupac hyperbaric ventilator. *SPUMS J* 1989; 19(4): 172-176

4 McDowall DG. Anaesthesia in a pressure chamber. *Anaesthesia* 1964; 19(3): 321-336

5 Handell S, Ansjou R, Casto R and Lind F. Respiratory CO_2 monitoring of the critically ill patient in the multiplace chamber. *Proceeding of the Joint Meeting 3rd Swiss Symposium on Hyperbaric Medicine and XVIIIth EUBS Annual Meeting held in Basel September 15-19 1992. ISBN 3-908229-00-6.* Basel: Foundation for Hyperbaric Medicine, 1993: 59-61

6 Skinner MW. Ventilator function under hyperbaric conditions. *SPUMS J* 1998; 28(2): 62-71

7 Sykes MK, Vickers MD and Hull CJ. Principals of Measurement and monitoring in Anaesthesia and Intensive Care. 3rd Edition. Town of publication: Publisher, 1990

This investigation was carried out in the Department of Anaesthetics and Intensive Care Townsville General Hospital, Eyre Street, Townsville, Queensland 4810, Australia when Dr Whittle was a registrar in the department.

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