Afr. J. Med. med. Sci. (1998) **27**, 81-84

Oxygen injector ventilation in adults and children: use of a variable pressure driving gas valve and a right angled connector

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Summary
An oxygen injector system (Harwill Medical, South Africa) was tested for ventilating intubated patients. There were 21 adults and 25 children. The system incorporates a variable pressure reducing value and a right-angled end connection with a 14 gauge oxygen exit nozzle and a 12 mm side port to atmosphere. Intravenous propofol was used to maintain anaesthesia, while the patients underwent alternate 10-minute periods of ventilation with the oxygen injector or an Ohmedia 7000 ventilator. Tidal volumes (ml/kg) achieved by mechanical ventilation were 8.06 ± 1.89 in adults and 7.28 ± 2.01 in children, compared with 5.79 ± 2.13 and 4.57 ± 1.58 respectively, with the oxygen injector ($P > 0.05$). Peak airway pressures (cmH_2O) on mechanical ventilation were 18.61 ± 3.06 and 20.21 ± 2.89 in adults and children. The corresponding pressures with the oxygen injector were 19.42 ± 3.97 and 18.49 ± 3.27 ($P > 0.05$). Cardiovascular parameters were unchanged. A side port adaptation provided a suction capability for water at a rate of 9.16 ml/s. We conclude that this system is an effective universal ventilator suitable for short-term ventilation and suction of patients.

Keywords: *Oxygen injector, Total thrust, Pulmonary ventilation, Suction.*

Résumé
Un systeme injecteur d'oxygene (Hardwill Medical, Afrique du Sud) a été testé pour ventiler des patients entubés. Ils étaient 2 adultes et 25 enfants. Le systeme incorpore une pression variable reduisant la valve et la connection de l'angle terminal droit avec une quotarzieme gauge de sortie d'oxygene et sortie de cote donnant sur l'atmosphere mesurant 12 millimetre. La profpofol intraveineuse de 12 millimetre a été utilisé pour maintenir l'anestesie, alorsque les patients ont subit l'alternance de la periode de 10 minutes de ventilation avec l'infecteur d'oxygene ou un ventilateur de marque Ohmeda 7000. Les Volumes (ml/kg) realises par la ventilation mechanique ont été de 8.06 ± 1.89 chez les adultes et de 7.28 ± 2.01 chez les enfants, comparé à 5.79 ± 2.13 et 4.57 ± 1.58 respectivement avec l'infecteur d'oxygene (P 0.05). Le pick de la pression du flux aerien (CmH_2O) sur la ventilation mechanique ont été de 18.6 ± 3.06 et 20.21 ± 2.89 chez les adultes et les enfants respectivement. Les pressions correspondantes avec l'injecteur d'oxygene ont été de 19.42 ± 3.97 et 18.49 ± 3.27 (P 0.05). Les parametres cardiovasculaires ont été inchanges. L'adaptation d'une ouverture de coté a procuré une capabilité de succion pour l'eau à un taux de 9.16 ml/seconde. Nous avons condut que ce systeme est un ventilateur universal effectif et proprice pur la ventilation à court terme et al succion des patients.

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Introduction

The Sanders' oxygen injector [1] is commonly used to ventilate patients undergoing endoscopic procedures of the upper airway [1,2,3]. The oxygen delivery toggle switch is easily operated by one hand, leaving the operator's other hand free for use. This suggests that this low-maintenance and easy to operate system is suitable for short to medium-term ventilation while transporting patients, or in field conditions [4].

An adaptation of this system (Harwill Medical, South Africa) was tested in the operating theatre. It has a rapidly interchangeable suction facility via a side port. Thus, a single operator may ventilate a patient and perform intermittent suction as needed.

While the venturi principle [5] applies to the suction adaptation, different principles, [6,7] apply to the pulmonary ventilation, i.e., momentum flux and total thrust. This implies that air entrainment plays a variable role in determining the volume of gas entering the lungs. Using the modified oxygen injector system, we investigated the air entrainment capacity, airway pressures obtained, clinical efficacy of pulmonary ventilation and suitability of use in children and adults. The suction capability was also tested.

Method

Twenty-one adults over 18 years of age and 25 children under 12 years were studied. All were ASA I or II, scheduled for general surgical or orthopaedic procedures. The patients or their parents signed informed consent forms and the hospital Ethical Committee gave permission for the study.

Premedication was with oral midazolam 0.5 mg/kg [8] up to a maximum of 7.5 mg, given one hour before anaesthesia. Children were induced and intubated with halothane in oxygen and air, while adults received a propofol induction and 2% lignocaine spray for intubation. Children were intubated with uncuffed Magil pattern endotracheal tubules of appropriate size. Adult females and 8 mm and adult males and 8.5 mm internal diameter cuffed endotracheal tubes. The anaesthesia was maintained with intravenous propofol throughout the study [9]. Standard cardiovasucular and respiratory monitors were used. A respiratory ratio of one to one was used and the rate was set to provide an expired carbon dioxide (Co_2) level of 4-4.5%.

A cardiocap monitor (Datex Instrumentarium Corp., Finland) was used for measuring expired (CO_2), expired oxygen (O_2) and digital O_2 saturation. The expired tidal volumes were measured with an Ohmeda 5420 tidal volume monitor (B.O.C. Health Care, U.S.A). This assembly was attached to the patient's endotracheal tube with a standard 15 mm side ported pressure connector for a Mallinkrodt anaeroid pressure gauge (Mallinkrodt Medical, Ireland).

Patients were randomly assigned to ventilation with oxygen injector device or with an Ohmeda 7000 ventilator (B.O.C. Health Care, U.S.A.) and a CO_2 absorber circle system using 40% inspired oxygen in air and peak inspiratory pressures of 20 cm of water The respiratory rate was adjusted to give an expired CO_2 level of 4-4.5%.

This paper was presented at the All Africa Anaesthetic Congress, Harare, Zimbabwe, 6-10 April, 1997

Patients were ventilated with one device for 10 minutes and then ventilated with the alternative method for 10 minutes, thus becoming their own controls. When using the oxygen injector in children, the driving valve pressure were adjusted to provide the best clinical conditions as judged by chest movement and the measured parameters as per points ii and iii below. Adults had the driving valve pressure set at 400 kPa. At the end of each 10-minute period, the following parameters were assessed:

i. Physical parameters: driving pressures in children, expired tidal volumes, airway pressures.
ii. Gaseous exchange: expired O_2 concentrations, expired CO_2 levels, digital O_2 saturations.
iii. Cardiovascular stability: blood pressure and pulse.

Airway pressures were measured at the time that constant O_2 injection produced a pressure plateau, [10] with the entrainment port open to the atmosphere. The entrainment port was then digitally occluded, while simultaneously ceasing the oxygen inflow. True airway pressures were then measured, without a gas entrainer effect [5] on the measured side port.

The air entrainment ratio was tested by replacing the patient with a two litre low compliance anaesthetic black rubber reservoir bag (Phoenix, United Kingdom). The expired volume and expired oxygen concentrations were measured with the atmospheric port open and closed during inspiration, i.e. with and without room and air entrainment. Inspiratory time was one and half seconds, the mean time used in the adult ventilation study.

Suction capability was achieved by connecting a standard 6-mm plastic suction tube to the 12-mm atmospheric entrainment port. The right-angled connector was disconnected from the patient and attached to a two-litre disposable plastic unit which has gas exit ports superiorly and an 8 mm diameter central tube for delivery of the suctioned fluid to the base of the unit. This was used at a driving pressure of 400 kPa to suction water out of a calibrated container for 60 seconds. An adult Yankauer suction point was used.

Statistical analysis was with a student's t test for paired data in the case of the ventilation parameters and a Chi-squared test for the entrainment volumes assessment. A P value of < 0.05 was taken as significant. Results are presented as mean values and standard deviations.

Fig. 1 The oxygen injector system used showing the pressure control value and the hand toggle switch.

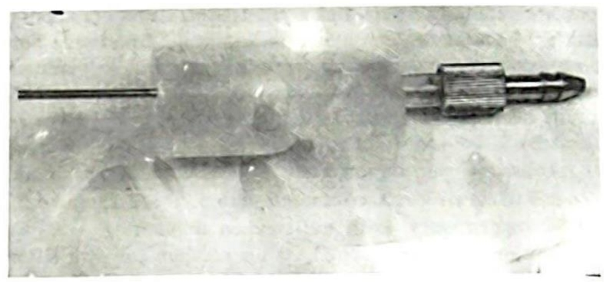

Fig. 2: The 15 mm right-angled connector with the central axis aligned to the 14 gauge delivery nozzle and a 12 mm expiratory side port of the atmosphere

Results

Twenty-one adults were studied. Their mean age was 41.82 ± 18.3 years and mean weight was 63.55 ± 17.91 kg. There were 25 children, mean age 4.97 ± 4.57 years and mean weight 19.19 ± 14.83 kg.

The physiological parameters were unaffected by the two modes of ventilation, expired CO_2 levels and digital O_2 saturations were unchanged and the cardiovascular parameters were the same (Table 1). This applied to adults and children, with an overall age range of 5 months to 82 years and weight range of 4.6 kg to 108 kg.

Table 1: The adult and paediatric parameters measured.

Group	Airway pressure port closed cm H_2O	Tidal volume ml/kg	Expired O_2 %	Expired CO_2 %	Digital O_2 Sats %	BP Syst Diast mmHg	Pulse
Adult							
I	19.42	5.79	90.38	3.96	98.86	115	85.68
	±3.97	±2.13	±6.24	±0.49	±0.73	71.61	±14.84
M	18.61	8.06	39.55	4.14	98.57	116.50	93.09
	±3.06	±1.89	±1.83	±0.51	±0.83	73.19	±13.71
Child							
I	18.49	4.57	97.86	4.74	99.56	95.80	104.92
	±3.27	±1.58	±1.97	±0.94	±1.98	53.32	±25/91
M	20.21	7.28	43.12	4.66	99.20	93.72	104.56
	±2.89	±2.01	±2.05	±0.71	±1.73	51.96	±24.87

All readings had
$P > 0.05$.
I = Oxygen injector
M = Ohmeda ventilator.

With the atmospheric port open, the airway pressure increased to plateau at approximately 1.5 seconds, thereafter not increasing with increased isnpiratory time. When the atmospheric exhaust port was closed at the inspiration plateau pressure, measured airway pressures (ture pressure) rose by 50% (Table 1). The tidal volumes were not increased by increasing the inspiratory phase beyond that needed to achieve the initial plateau airway pressure. The oxygen injector provided tidal volumes 28-37% less than that obtained with mechanical ventilation, but this did not reach significance, $P > 0.05$. Table shows that the tidal volumes in children of different weights remained constant, despite different driving gas pressures used for them. While the mean airway pressure in children 18.49 ± 3.27 cmH_2O, was similar to that for adult at 19.42 ± 3.97 cmH_2O, small children weighing below 10kg achieved low airway pressures of 14.37 ± 3.75 cmH_2O at a driving gas pressure of 100 kPa.

Table 2. The driving pressures used at different paediatric weights are given. Tidal volumes were not different, $P >$ 0.05. The airway pressure achieved in the under 10 kg group was significantly less than that obtained in the over 25 kg group, $P < 0.05$.

Driving pressures kPa	200	300	400
Weight kg	< 10	11-25	> 25
Numbers	8	10	7
Tidal volume	4.58	3.89	5.55
ml/kg	±1.72	±1.47	±1.57
Airway pressure cm water	14.37	18.30	23.33
cm water	±3.75	±3.19	±2.93

Table 3 shows the effect of air entrainment on the "tidal volume" increased by a factor of 3.5 when air entrainment was allowed. However, the tidal volume was 511 ± 11 ml when no entrainment took place. In adult patients, a mean tidal volume of 368 ± 135 ml was achieved with the entrainment port open.

The suction capability was 552 ml of water in 60 seconds at a uniform rate.

Table 3: The expired tidal volumes and expired oxygen concentrations achieved with the oxygen injector used to ventilate a two-litre anaesthetic reservoir bag. With the atmospheric port open, the expired tidal volume is significantly greater and the expired oxygen concentration is significantly less than that obtained with the atmospheric port closed ($P < 0.01$).

Atmospheric port	Open	Closed
Tidal volume (ml)	1802	511
	±164	±11
Oxygen expired (%)	42	100
	±196	±0

Discussion

The oxygen injector system (Harwill Medical, South Africa) used in this study is shown in Figure 1. It function from a 400 kPa pressure supply via a high-pressure hose. The inline pressure reducing value [2] allows the driving pressure to be altered between 100 and 400 kPa, then locked at the pressure setting. Oxygen exists via a 14 gauge stainless steel nozzle, centrally aligned in the axis of a right-angled connector. This connector has a 15 mm diameter fitting that attaches to a standard endotracheal tube connector. It has a right-angle arm with a 12 mm internal diameter orifice, open to the atmosphere, Fig. 2. This allows air to be entrained and provides "infinite" compliance [6]. Alongside the pressure reducing value, a hand-controlled toggle switch determines the duration of inspiration and expiration.

When used to ventilate the lungs, an oxygen injector system does not function as a Venturi system [6,7] and air entrainment plays a minor part in the tidal volume delivered. Isabey et al [6] have shown that for a given driving pressure, gas injected into the airways results in tidal volumes determined by the "momentum flux" principle. The momentum flux, d.f.v (d = gas density, f = flow rate, v = mean velocity), is constant along the jet axis [5]. Thus, when the velocity of the injected gas decreases, the total flow increases and this requires the entrainment of some air. When turbulence develops, as in the trachea, an extra component needs to be added in the form of lateral pressure times cross-sectional area. This gives "total trust" and is shown to remain almost constant along the jet axis in axis symmetrical confined jets [7]. In the trachea, an unknown part of the entry total thrust is lost in wall friction, thus, it decreases along the airway and lower airway pressure will be less than upper airway pressure [6,7].

The above results in relatively little air entrainment and this was demonstrated in the moderate tidal volumes and high expired oxygen concentrations we achieved. In ventilating the anaesthetic reservoir bag without air entrainment, tidal volumes of 511 ± 11ml were obtained. This was 38% more than that achieved in adults when air entrainment took place. With full air entrainment, the reservoir bag's tidal volumes were nearly five times greater than that seen in adult patients. The expired oxygen concentration in adults was 90.38 ± 6.24%, implying air entrainment of 12.65%. In children, the expired oxygen concentration was 97.86 ± 1.97% and air entrainment would have been a minimal 2.81%.

The relatively low tidal volumes achieved are explained by the concept of plateau or "stalling" pressure [10]. This is the pressure at which equilibrium is achieved between gas entry into the airways and gas exit via the exhaust port to the atmosphere. As momentum flux and hence total thrust are fixed for a specific driving pressure, [6,7] once maximum airway pressure is achieved, no further gas volume movement will occur into the lungs.

The combination of a high inspired oxygen concentration and a low tidal volume has implications for the potential complications of oxygen absorption atelectasis and pulmonary oxygen toxicity [2]. Therefore, only short-term ventilation is advised, such as for the transport of patients or for field surgery. Both hypo [11] and hyperventilation [6] are recognized complications of jet ventilation. The routine use of peripheral oximetry is recommended to ensure oxygenation. In addition, the use of capnography will ensure that adequate alveolar ventilation takes place. In a field situation, clinical judgement based on chest movement and the colour of mucous membranes may be the only criteria available to the medical personnel.

Barotrauma [3] is a well-described danger with jet ventilation and may result in mucosal stripping, cervical or mediastinal emphysema and a pneumothorax [2,1]. This is especially relevant in children where an increased ventilatory pressure may be used in an attempt to increase the tidal volume. We found that each 100 kPa increase in the ventilatory pressure provided a greater than 50% increase in the tidal volume, but at the cost of a similar increase in the airway pressure. Barotrauma has two likely causes, the commonest of which is direct pressure build up in the lungs [3]. However, that is unlikely to be relevant to the Harwill system provided the 12 mm side port remains unobstructed. The other cause of barotrauma is the oxygen exiting from the nozzle in a narrow jet stream at the present ventilating pressure [11]. As this system is designed to be used with an endotracheal tube, this second cause of barotrauma is unlikely to be a problem. Pressure fall-off from the nozzle exiting pressure to that of the mean achieved airway pressure, occurs within a length equivalent to six diameters of the entry chamber [6,12], i.e, the endotracheal tube. By the time the inflating gas enters the trachea from the endotracheal tube, safe pressure are likely to be present. Nevertheless, the operator must ensure that the atmospheric side port remains unobstructed. By avoiding an excessive rise in the mean intrathoracic pressure, venous return to the heart remain stable [3,11] and the blood pressure and pulse remain unaffected.

A further complication, resulting from the dry gases expanding into the air passages, is desiccation of the mucosa [11]. This can be minimized by injecting small amounts of normal saline down the endotracheal tube to prevent excess drying when moderately prolonged ventilation is expected.

The 14 gauge oxygen delivery nozzle proved to be suitable for patients aged from five months to eight-two years. When no pressure control valve is used, other researchers have controlled the tidal volume and the airway pressure by means of exchangeable nozzles or various diameters. [2,11]. In adults, 13 to 15 gauge nozzles are advised and 16 to 18 gauge nozzles for children. These have been used at driving pressures of 400 kPa. We feel that an exchangeable nozzle runs the risk of dislodgement and impaling the patient. A fixed 14 gauge nozzle with a variable pressure reducing value for the ventilation gas seems more appropriate.

The right-angle connector point allows a lone operator to ventilate a patient and to rapidly change to the Venturi suction [5] capability when needed. This provides efficient suction at a volume of 9.16 ml per second. This would be sufficient for the removal of routine secretions of a patient in transit.

We conclude that this oxygen jet ventilation system is easy to use, versatile across a wide range of patients, provides safe respiratory and cardiovascular parameters and that the suction facility is effective. In the African context, where technological maintenance facilities are limited, it provides effective short-term ventilation during the transport of patients or during field conditions.

Acknowledgements

Thanks to Mrs S. Norman for typing the manuscript, Harwill Medical Supplies for providing the apparatus and the patients who participated.

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