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Oxylator and SCUBA dive regulators: useful utilities for in-water resuscitation

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ABSTRACT

Introduction In water resuscitation has been reported to enhance the outcome of drowning victims. Mouth-to-mouth ventilation during swimming is challenging. Therefore, the efficacy of ventilation utilities was evaluated.

Methods Ventilation was assessed with the Oxylator ventilator, as well as the consecutive self-contained underwater breathing apparatus (SCUBA) regulators using an anaesthetic test lung: Poseidon Cyklon 5000, Poseidon XStream, Apeks TX 100, Spiro Arctic, Scubapro Air2 and Buddy AutoAir.

Results Oxylator, Apeks TX 100, Arctic and Buddy AutoAir delivered reliable peak pressures and tidal volumes. In contrast, the ventilation parameters remarkably depended on duration and depth of pressing the purge button in Poseidon Cyklon 5000, Poseidon XStream and Scubapro Air2. Critical peak pressures occurred during ventilation with all these three regulators.

Discussion The use of Poseidon Cyklon 5000, Poseidon XStream and Scubapro Air2 regulators is consequently not recommended for in-water ventilation. With the limitation that the devices were tested with a test lung and not in a human field study, Apeks TX 100, Spiro Arctic and Buddy AutoAir might be used for emergency ventilation and probably ease in-water resuscitation for the dive buddy of the victim. Professional rescue divers could be equipped with the Oxylator and an oxygen tank to achieve an early onset of efficient in-water ventilation in drowning victims.

INTRODUCTION

Drowning is a frequent cause of death in male adolescents and young adults[1] and is associated with a poor outcome, high lethality and high long-term morbidity,[2] especially when occurring in open water.[3]

Since a quick onset of oxygenation by bag-mask ventilation, or CPAP, with a high inspiratory oxygen concentration has been shown to be beneficial,[4 5] the recent resuscitation guidelines of the European Resuscitation Council prompt for a beginning of ventilation during rescue swimming straightaway.[6] A study by Szpilman and Soares[7] that retrospectively investigated the effect of in-water resuscitation (IWR)—that is, in-water ventilation—reported beneficial effects on survival rate and severe neurological damage: IWR appeared to reduce mortality and severe neurological damage significantly. Perkins *et al* investigated the efficacy of IWR[8]: Three lifeguards performed between seven and nine rescue breaths with sufficient tidal volumes over a 50 m distance in an indoor swimming pool. Moreover, there is a certain risk of aspiration and consequent laryngospasm or drowning for the lifeguard. Furthermore, the lifeguards reported the technique to be technically difficult and physically demanding even after this very short resuscitation period. For this reason, mouth-to-mouth ventilation might not be a proper choice when performed by untrained laypersons. As IWR seems to be challenging, it appears to be sensible to evaluate possible utilities. For this reason, the present study investigated the efficacy of ventilation with an emergency ventilator, as well as several commonly used self-contained underwater breathing apparatus (SCUBA) regulators.

METHODS

The efficacy and reliability of several ventilation utilities was assessed in a controlled laboratory setting. A Maquet anaesthetic test lung was ventilated using consecutive tools: Oxylator (CPR Medical Devices INC, Toronto, Canada) waterproof, pressure-controlled emergency ventilator, as well as commonly used SCUBA regulators: Poseidon Cyklon 5000, Poseidon XStream (Poseidon Diving Systems AB, Västra Frölunda, Sweden), Apeks TX 100 (Apeks Marine Equipment Ltd, Blackburn, England), Spiro Arctic (Aqua Lung La Spirotechnique IC, Carros, France), Scubapro Air2 (Johnson Ourdoors, Racine, Wisconsin, USA) and Buddy AutoAir (AP Valves, Helston, UK). The test lung was mounted on a Laerdal Resuscitation Anne (Laerdal Medical, Stavanger, Norway) and ventilated by regulator-to-mouth ventilation.

Ventilation with the Oxylator was performed using a disposable anaesthetic ventilation mask. For ventilation with SCUBA regulators, a tightened-up, well-fitting SCUBA mask—as used in almost every recreational dive—was used to reduce air losses via the manikin's nose. The SCUBA regulator was connected to the manikin by inserting the mouthpiece into the manikin's mouth and closing the jaws and lips with the thumb, third, ring and little fingers of the left hand. The index finger was used for pressing the purge button. For ventilation, the inspiration valve was activated via the purge button. The expiration valve was not controlled actively. Positive pressures required for ventilation were reached by ultra-high air flows resulting in an overload of both, the expiration valve as well as the leakages at the manikin's lips and nose. A one-handed (figure 1) or two-handed (figure 2) technique was used to fix the SCUBA regulator in place, close the jaws and lips and operate the purge

Figure 1 Test setting for the assessment of peak pressures. The hose attached to the upper airways of the manikin is directly connected to the Primus ventilator for pressure measurement. The one-handed technique is used to operate the SCUBA regulator.

button. The purge button was pushed to its maximum depth for 5 s to achieve inspiration, and released for 5 s afterwards for expiration. When critical pressures were reached, or the test lung was overinflated, the depth and time of pressing the purge button was reduced.

Peak pressures applied, as well as exspiratory tidal volumes, were measured using the monitoring unit of a Draeger Primus anaesthetic ventilator (Draeger-Siemens Medical AG, Luebeck, Germany). Before each series of measurements, the flow/volume sensor of the Primus ventilator was tested with a volume-calibrated Jaeger Master Scope spirometry pneumotachograph (Viasys Healthcare, Wuerzburg, Germany), and the pressure sensor with an independent electronic manometer. Differences in tidal volume <20 ml and in pressure <1 kPa were considered acceptable.

The test setup for pressure testing is presented in figure 1, and for tidal volume testing in figure 2.For technical reasons, peak pressure and tidal volumes delivered were tested in two separate series. The resuscitation manikin was directly connected to the Primus for the assessment of peak pressures. For tidal volume testing, the anaesthetic test lung was connected via a non-rebreathing valve. Before testing the utilities for IWR, the anaesthetic test lung was assessed using the Draeger Primus ventilator. For each ventilation utility tested, a series of 10 ventilations was performed. The Oxylator ventilator was tested with peak pressures adjusted to 20, 25, 30, 35, 40 and 45 kPa.

Microsoft Excel 2007, Microsoft Inc, Redmond, Washington, USA and SPSS V.19, SPSS Inc, were used for statistical analysis.

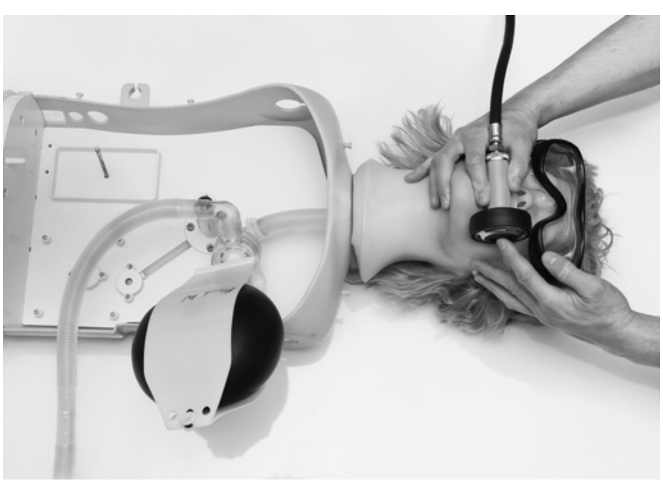

Figure 2 Test setting for the assessment of tidal volumes. The trachea-like hose of the manikin is connected to a non-re-breathable valve. The expiration branch is connected to the Primus ventilator to detect the expiratory tidal volumes of the test lung. The two-handed technique is used to operate the Poseidon Cyklon 5000 regulator. During ventilation with the Cyklon 5000, the test lung is overinflated.

RESULTS

The Oxylator ventilator reliably delivered the pressures adjusted and provided relatively constant tidal volumes (table 1). In contrast, there was a wide range in peak pressures and tidal volumes applied by the SCUBA regulators (table 1). The peak pressures and tidal volume delivered by Apeks TX 100, Spiro Arctic and Buddy AutoAir were within a relatively narrow range during the 10 ventilations tested. In contrast, there was a wide variation in Poseidon Cyklon 5000, Poseidon XStream and Scubapro Air2. Pressures and volumes applied by these devices remarkably depended on the duration and depth of pressing the purge button. Figure 2 demonstrates the overinflation of the test lung using a Poseidon Cyklon 5000 regulator.

DISCUSSION

According to the latest reports of the Divers Alert Network, frequent causes of death during SCUBA dives are pre-existing internal ailments like coronary heart disease, apart from drowning.[9–11] For this reason, an early onset of ventilation appears to be beneficial for the patient. Since mouth-to-mouth ventilation during towing appears to be time consuming and breath-consuming and potentially risky for the rescuer,[12] other ways of mechanical ventilation should be taken into account. In SCUBA diving, each diver is usually accompanied by a buddy, that is, a second diver. If drowning or cardiac arrest occurs in one of the divers, the buddy should be able to start resuscitation efforts immediately.

Table 1 Peak pressures and tidal volumes

System	Peak pressure (kPa), mean ± SD (range)	Tidal volume (ml), mean ± SD (range)
Primus: 15 kPa	15±0 (15–15)	261.4±3.0 (258–266)
Primus: 20 kPa	20.9±0.7 (20–22)	428.8±2.5 (425–433)
Primus: 25 kPa	26.1±0.8 (25–28)	713.5±2.0 (710–716)
Primus: 30 kPa	32.3±0.6 (31–33)	774.9±2.4 (771–779)
Primus: 35 kPa	37.4±0.5 (37–38)	824.5±2.5 (821–829)
Primus: 40 kPa	42.7±0.8 (41–44)	867.1±2.2 (864–871)
Poseidon Cyklon 5000	66.9±9.7 (57–88)	1121.1±278.5 (526–1488)
Poseidon Xstream	79.8±20.7 (49–99)	931.2±375.3 (578–1995)
Apeks TX 100	37.9±1.8 (34–41)	751.9±48.6 (703–834)
Spiro Arctic	26.5±1.7 (24–31)	512.2±37.2 (447–577)
Buddy AutoAir	13.2±0.7 (12–14)	265.2±17.1 (226–286)
Scubapro Air2	82.3±12.9 (62–99)	1497.2±106.1 (1265–1620)
Oxylator: 20 kPa	20.3±0.6 (19–21)	298.8±10.4 (284–313)
Oxylator: 25 kPa	25.2±0.6 (24–26)	327.7±18.1 (307–367)
Oxylator: 30 kPa	27.9±0.5 (27–29)	406±8.4 (392–418)
Oxylator: 35 kPa	33.2±0.9 (32–35)	564.6±10.3 (553–584)
Oxylator: 40 kPa	38.3±0.8 (37–40)	666.5±32.2 (572–691)
Oxylator: 45 kPa	43.1±0.8 (41–44)	708.5±10.0 (689–720)

Data are mean ± SD (range).

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Apart from SCUBA diving accidents, drowning is also a frequent cause of death in young males, as pointed out in the introduction.

Ventilation with professional ventilation devices

In several countries all around the world, specialised rescue forces have been set up to localise and rescue drowning victims. In case of an emergency call reporting a drowning accident, these forces are transferred to the drowning site within a few minutes via helicopters or special ambulance cars. In many countries, professional water rescue forces consist of specialised rescue divers whose training and equipment are primarily optimised for search and rescue operations. One potential extension of these rescue divers' equipment is the Oxylator. The Oxylator is a rugged emergency ventilator that is absolutely waterproof. In the present study, the Oxylator pressure-controlled ventilator provided reliable ventilation. Since the Oxylator can be used with a mask, laryngeal tube or tracheal tube, it seems to be a potentially helpful tool for rescue forces. Rescue divers, for example, might be equipped with the Oxylator device—either attached to their own breathing air tank or to a separate oxygen tank. In this manner, the patient could be ventilated easily while being towed to the boat or the shore using a mask. As soon as operation conditions are better, for example, at land or on board the rescue boat, thorax compression can be started and the patient can be intubated with a laryngeal or better tracheal tube. In severely hypoxaemic drowning victims, high positive end expiratory pressure (PEEP) pressures are required to ensure sufficient ventilation.[13]

By using the Oxylator, rescue swimming can be performed quickly without exhausting and time-consuming interruptions for rescue breathing, and ventilation is expected to be more constant. Furthermore, inspiratory oxygen fraction can be set to 1.0 when using a separate oxygen tank instead of an inspiratory oxygen fraction as low as approximately 0.17 in mouth-to-mouth ventilation. If in-water resuscitation improves the outcome of drowning victims, the use of the Oxylator device is quite likely to offer better conditions than conventional mouth-to-mouth ventilation.

However, there are some limitations using the Oxylator which should be addressed. First, the PEEP level cannot be adjusted manually and is set to approximately 3–5 kPa which is quite low in intubated drowning victims. Second, the Oxylator is a pressure-controlled ventilator, that is, tidal volumes applied, highly depend on the compliance of the patient's lungs.[14] Therefore, tidal volumes might vary during the rescue process.[15] Nevertheless there are also studies reporting less stomach insufflations,[16] more reliable tidal volumes and a greater chance of normocapnia[17] when using the Oxylator compared with bag-mask ventilation.

Improvised ventilation with SCUBA regulators

In contrast with swimmers, the SCUBA diver is equipped with a tool potentially suitable for ventilation: his SCUBA breathing regulator. In the present study, we tested the peak pressures and tidal volumes applied by frequently used regulators. Surprisingly, the experimental testing of the regulators' purge function for artificial ventilation revealed a wide range in acquirable pressures and volumes. While Apeks TX 100, Spiro Arctic and Buddy AutoAir provided reliable and reproducible ventilation parameters, Poseidon XStream, Poseidon Cyklon 5000 and Scubapro Air2 did not appear to be suitable tools for in-water ventilation. In the Scubapro and the two Poseidon regulators, the expiration valves were not able to relieve the breathing air delivered at very high flow rates. This air trapping resulted in critically high peak pressures: up to 88 kPa in the Poseidon Cyklon 5000 and 99 kPa in the Poseidon XStream and the Scubapro Air2 regulators. For this reason, we strongly recommend not to use these regulators for purposes of in-water resuscitation. Lower peak pressures and tidal volumes can be achieved by light and short pressing of the purge button, but it does not seem to be realistic that the rescuer can achieve proper ventilation parameters in a resuscitation setting using such devices. In contrast, the stable parameters delivered by Apeks TX 100, Spiro Arctic and Buddy AutoAir with full pressing of the purge button and independent of the duration of pressing appear to be suitable for rescue ventilation in this experimental setting. In previous studies, ventilation using a modified SCUBA regulator[18,19] for in-water resuscitation and a modified closed-circuit re-breather for out-of-water resuscitation[20,21] has been investigated. However, modification of such essential devices as SCUBA regulators may result in loss of manufacturer's warranty, device failure, severe injury or even death. Therefore, our aim was to evaluate non-modified commonly used devices that are likely to be available with a large number of divers.

Which of our tested devices should preferably be used for rescue ventilation depends on the personal emphasis; whether it is more important to avoid stomach insufflation by using low pressures (mean peak pressure 13 kPa in Buddy AutoAir), or to obtain high pressure levels (27 kPa in Arctic and 38 kPa in Apeks TX 100) for optimal oxygenisation.

Practical in-water use

According to rescue swimmers, rescue divers and lifeguards who tested the devices in open water, they were easy to use and did not remarkably delay the towing and rescue process. The control of the purge button with a cycle of 5 s of pressing and 5 s of releasing was easy to perform. However, a precise assessment of ventilation parameters achieved in open water has not been performed yet.

Several diving associations recommend the mouth-to-mouth or mouth-to-snorkel ventilation of injured divers without spontaneous breathing. Up to today, there is no reliable data supporting efficacy of these recommendations associated with a potential threat to the rescuer due to aspiration of exhaust. Therefore, ventilation via Oxylator or SCUBA regulator is expected to be safer and more efficient due to a better compensation of leakages achieved by ultra-high gas flows.

In general, manikin studies do not necessarily reflect the ventilation characteristics of the real human body, especially when dressed with a dive suit. However, human experiments on the feasibility of in-water ventilation cannot be performed for ethical reasons. Further studies are required.

CONCLUSIONS

Both, robust ventilators like the Oxylator as well as improvised solutions like the Apeks TX 100, Spiro Arctic or Buddy AutoAir SCUBA regulators seem to be useful tools for in-water ventilation. These SCUBA regulators are relatively easy to use since pressures and tidal volumes were relatively constant when pressing the purge button as deep as possible for a period of 5 s. However, legal aspects should be taken into account when ventilating with improvised devices. In contrast, SCUBA regulators are not viable for ventilation when the pressures and tidal volumes depend on the duration and depth of pressing the purge button. Further investigations, for example, in animal or field studies are required.

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