

Application of a Cuirass and Institution of Biphase Extra-Thoracic Ventilation by Gear-Protected Physicians

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Objectives: To evaluate the speed by which cuirass application, followed by biphasic extra-thoracic ventilation, can be instituted by full anti-chemical protective gear-wearing physicians.

Materials and Methods: Ten physicians of variable subspecialties applied a cuirass on an adult volunteer and instituted biphasic extra-thoracic ventilation, using the RTX respirator (Medivent, London, UK). Endotracheal (ET) intubation and manual ventilation of a mannequin and its ventilation was comparatively assessed. Performances were conducted in a prospective, crossover, randomized manner. Times to successful applications as well as failure rates were recorded.

Results: Cuirass application was performed more rapidly (102 ± 9 s, 177 ± 31 s, respectively, $P < .01$) and with a slightly lower failure rate than ET intubation.

Conclusions: Physicians wearing full anti-chemical protective gear applied the cuirass and instituted biphasic extra-thoracic ventilation faster than ET intubation and manual positive pressure ventilation. Extra-thoracic ventilation should be further evaluated as an option for emergent respiratory support during toxic mass casualty events.

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EMERGENT VENTILATION has become recently an important issue, because the threat by weapons of mass destruction has become real. Respiratory failure following exposure to agents that are toxic to the airway may lead to death unless intervention is immediate. Hence, medical caregivers may be required to intervene while wearing full protective gear that hampers dexterity and speed of performance.

Endotracheal (ET) intubation followed by positive pressure ventilation is currently the “gold standard” for airway control and emergency respiratory support in patients with cardiac or respiratory arrest. It is also considered the procedure of choice in cases of mass casualties, including those involving exposure to toxic material.¹ Nevertheless, in such a scenario, shortage of qualified personnel capable of quickly and unmistakably managing patients’ airways can be anticipated, especially in

performing laryngoscopy, while wearing an anti-chemical protective gear.²

The RTX respirator (RTX; Medivent, London, UK) is a user-friendly portable respirator, which provides external high frequency oscillation by way of a cuirass tightly fitted around the patient’s chest. Oxygenation and carbon dioxide exchanges are as effective as during positive pressure ventilation.³ The apparatus is capable of ventilating a wide range of subjects, including infants and obese adults, for whom appropriate sizes of the cuirasses are commercially available. Both the inspiratory and expiratory phases are active and the chest is oscillated due to predetermined negative inspiration and positive expiration pressures thereby applied. The system was found to be clinically effective when using pressures that range between -25 and $+15$ cm H₂O, inspiratory/expiratory (I/E) ratios between 1/1 and 1/3 and frequencies of 60-150 cycles per minute (CPM) (Fig 1).³⁻⁷ Recently, our group reported the feasibility of resuscitating cats suffering from organophosphate intoxication by using an earlier version of the RTX respirator. Prevention of death from apnea or suffocation and a high survival rate were attained with the cuirass-based extra-thoracic ventilation.⁸

The aim of the present study was to assess the speed by which respiratory support can be instituted by biphasic extra-thoracic ventilation by using a cuirass and the RTX respirator by full anti-chemical protective gear-wearing physicians. We comparably assessed the performance of ET intubation followed by standard manual positive pressure ventilation.

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0883-9441/04/1901-0006\$30.00/0

doi:10.1016/j.jcrc.2004.02.007



Fig 1. The RTX portable respirator (Medivent) and the cuirass attached to a volunteer.

MATERIALS AND METHODS

Respirator and Endotracheal Equipment

The RTX is a relatively small ($14 \times 14 \times 18$ cm), lightweight (2 kg) rugged respirator. It is a modern version of the known Hayeck Oscillator (Medicom, Hendon, Middlesex, UK), used for respiratory support in both adult and pediatric patients.⁹⁻¹¹ The respirator functions via a battery-operated microprocessor-controlled power unit. A turbine which is connected to the power unit forces gas in-between disk valves, thus generating an oscillatory movement that operates over a wide range of frequencies (6-1200 CPM) and pressures (-50 to $+50$ cm H_2O). The frequency, the inspiratory, and expiratory cuirass chamber movements and I/E ratio are automatically (as was the case in this study) or manually preset and are controlled by a negative feedback loop operated with the aid of a pressure sensor.¹² Since both the inspiratory and expiratory phases are time- and amplitude-preset, high frequencies can be achieved. This is in contrast to common negative pressure respirators in which the expiratory phase is passive following the

recoil of the chest, thus significantly limiting attainable frequencies.

The battery (1 kg) that supplies the respirator has a maximum life of 4 hours. Because of these characteristics, rescue personnel can easily carry the respirator even when wearing protective gear or when carrying other equipment. It can, therefore, be deployed and operated in any indoor or outdoor location without difficulty.

The cuirass (Fig 1) consists of a flexible, lightweight transparent hard plastic that covers the anterior part of the chest and upper abdomen, having a wide foam rim, which creates an airtight seal with the skin or adapts to underlying clothing without air leak. It is secured to the body by 2 straps and is connected to the respirator itself by wide-bore (22-mm) flexible tubing. The cuirass is available in 10 different sizes according to patient weight or age.

A 7.5 mm ID cuffed lubricated endotracheal tube (Portex; SIMS Portex Ltd, Hythe, Kent, UK) was used during the comparative part of the study of mannequin airway management (Laerdal Air-

way Management Trainer; Medical Plastics Laboratory–MPL, Gatesville, TX).

Study Protocol

Ten physicians from different subspecialties (3 family physicians, 2 pediatricians, 1 internal medicine, 2 general surgeons, 1 neurologist, and 1 psychiatrist) participated in the study, which took place in a university-affiliated community hospital. None of the physicians had previous experience in the treatment of toxic mass casualties or in working under protective conditions. All wore an anti-chemical warfare gear, which included a personal full-body plastic suit, rubber gloves, and a gas mask with an attached filter. Several hours before the study, the same physicians (with the gear off) were instructed first how to perform an ET intubation and then how to operate the cuirass and the RTX respirator, using both instruction manuals and a demonstration on a mannequin and on a volunteer, respectively. The duration of each training period lasted 30 minutes. When starting the study, each participant intubated the mannequin or applied the cuirass onto a volunteer in a random, crossover sequence. Randomization was based on computer-generated codes that were maintained in opaque envelopes until 5 minutes before approaching the devices. A maximum of 2 attempts was allowed to successfully perform each maneuver.

ET intubation was defined as successful when adequate expansion of the dummy's chest was obtained when applying manually positive pressure ventilation using an ambu bag (Laerdal ambu; Medical Plastics Laboratory). Proper placement of the tube was then documented by a laryngoscopy performed by an external expert observer. Intubation time was measured from the moment the physician reached for the ET until positive pressure ventilation was performed (visible chest inflation). This time also included the preparation of the ET equipment (ie, lubrication of the tube, insertion of a guide through it, and verification of the cuff and laryngoscope being undamaged).

The cuirass was connected to a volunteer who was lying fully dressed on a stretcher. Time to apply the device was measured from the moment the cuirass was held by the participant until the institution of negative extra-thoracic ventilation (ie, chest inflation). Successful attempt was defined as visible inflation of the thoracic cage following the switch-on of the RTX respirator, confirmed

Table 1. Endotracheal Tube Insertion and Cuirass Application (see text, mean \pm SD)

	Endotracheal Intubation	Cuirass Application
Time to successful application (s)	177 \pm 31*	102 \pm 8.7
Failure during 1 st attempt (n)	4	1
Failure during 2 nd attempt (n)	2	0

* $P < .01$ v. the cuirass value.

visually and by auscultation performed by the independent observer. Failure was declared when the chest did not expand after cuirass connection to the respirator.

Data Analysis

All values are expressed as means \pm SD. A prestudy power table where delta (the mean difference in velocity of performance recorded in a pilot study) between the 2 groups (ET = 133 \pm 11, cuirass = 117 \pm 10), alpha = 0.05 and power = 0.94 resulted in the need for a minimum of 10 patients in each group. Data were analyzed by using the unpaired *t*-test, especially in view of possible dropouts among the groups. Fisher Exact test was used to analyze failure rates. Alpha value < 0.05 was considered significant.

RESULTS

Table 1 describes the performances of the physicians when applying each of the devices. The physicians applied the cuirass and instituted external respiration significantly faster than ET intubations were; only 1 case of failed implementation was recorded among the former versus 6 among the latter ($P > .05$). When placement of the cuirass was not adequate or if the caregiver forgot to switch-on the respirator at the first attempt, these were corrected on the second attempt. Reasons for failure included inability to visualize the vocal cords of the mannequin and inability to tightly apply the cuirass. No equipment-related failure occurred.

DISCUSSION

Using a feline model for severe and multifacet respiratory failure similarly to that occurring after exposure to nerve agents (eg, central apnea, bronchorrhea, bronchospasm, and pulmonary edema), we were able to resuscitate apneic cats for as long as 3 hours using a cuirass-based extra-thoracic negative-positive pressure ventilator.⁸ These en-

couraging results paved the way for the present assessment of the ease of applicability of the cuirass-based negative pressure ventilation in humans. We indeed found that the cuirass could be applied and biphasic extra-thoracic ventilation instituted by previously inexperienced gear protected physicians by >40% faster than they intubated the mannequin and ventilated it. The latter reported a slightly higher failure rate. The present ET data are not unexpected also since it was shown previously that protective gear could impair visual acuity and manual dexterity of medical personnel¹³ or, in case of exposure to toxic agents, cause severe miosis or blurred vision, disabling the physician from performing laryngoscopy.¹⁴ Also, none of the physicians was an anesthesiologist or had previous practice in performing ET intubation. Indeed Goldick et al¹⁵ also reported of longer time needed for successful ET intubation as compared to laryngeal mask insertion in monkeys by anesthesiologist wearing protective gear. In their report, the average time for intubation was shorter (by <30 s) than we measured, probably because it was conducted by experienced anesthesiologists and because they did not include in the reported time the preintubation assessment.

Recent data have pointed out that 25% of endotracheal tube placement during conventional prehospital emergencies were misplaced, carrying with it ~50% death rate.¹⁶ A higher failure rate of ET intubation is to be further anticipated among unskilled caregivers, when acting within a chaotic setting.^{2,17-19} especially if previously inexperienced in ET intubation.²⁰ Hence, equipping the first unit of medical caregivers with alternative and easy means for basic respiratory support might be of additional value until a more advanced life support is obtainable. Recently, different kinds of supraglottic airway control devices have also been put into the market,²¹ and they have been studied regarding their potential use in toxic mass casualty events.¹⁵ While these devices do not need direct laryngoscopy, their application still requires previous experience. In addition, the fixation of the supraglottic devices around the patient head and neck, similarly to ET tube, could be a laborious procedure when the caregiver is wearing protective gloves.^{2,22} In contrast, the simplicity by which the cuirass can be applied to the victim's chest enables the reliance on fewer and less trained medical staff.

In this regard, the adhesive nature of the foaming ring keeps it tightly sealed to the patient's thorax even when the cuirass is applied on clothing. This saves time and much effort to undress the victim in the prehospital area. Our group of physicians were of a mixed medical subspecialties who, based on local civilian protection plans, would be deployed as rescue teams in Israel, ie, lacking expertise in acute care or trauma management. It is thus plausible that a less sophisticated and invasive method of ventilatory support would be applied faster and, at the same time, might produce less anxiety among the victims than an invasive (ie, ET intubation) one.

Systemic toxicity from organophosphorous nerve agents is associated with bronchorrea.² Repeated active drainage of bronchial secretions is a major component of the respiratory care of the intoxicated patient, for which ET intubation is the best choice. Nevertheless, optimal clearance of secretions was obtained when the biphasic cuirass-based external high frequency oscillation was used.⁸ It can be attributed to the reduction in sputum viscosity and enhancement of ciliary clearance due to the active expiratory phase.^{8,23} In this regard, effectivity of bronchorrea clearance during emergency ventilation using the RTX respirator during toxic mass casualty, await clinical proofs.

This study has several limitations: it was not our original intention to compare between the effectiveness of ET intubation and successful positive bag-valve ventilation and the application of the respirator followed by cuirass-based ventilation. Nevertheless, once a new technique of ventilatory support is introduced, it must be judged against the "gold standard," ie, ET intubation. Also, we did not specifically address the issue of pediatric ventilation (ie, choosing the right size in order to create an absolute seal on a child's thorax). We rather used 1 size (adult) cuirass to test the device's feasible use under the given circumstances. In addition, we performed our study on this relatively new technique of ventilation in an open manner, thus allowing for a possible bias being introduced by the enrolled physicians. Importantly, this extra-thoracic device can not be used in specific trauma victims who, in addition to toxic gas inhalation, also suffer from injuries to the thorax and/or abdomen. In addition, oxygen supplementation using this technique is cumbersome as compared to nor-

mal positive pressure ventilation via an ET tube using a portable ventilator and an attached oxygen source. Also, the simulated contaminated environment is problematic to the use of the extra-thoracic respirator, since in the given conditions, the RTX respirator would use contaminated air to ventilate the patient. This could also be the case if using an ET tube and an ambu bag, unless an antichemical gas filter is applied to the inflow port of the bag, which is doubtful under such circumstances. Furthermore, its presence could impede air movement because the filter could be stacked by the amounts of secretions, equally resulting in the patient's asphyxia. Thus, while the authors are of the opinion that the degree of upper airway protection from toxic elements provided by the cuirass-based ventilation is inferior to that provided by the standard ET intubation, the application of the former as an emergent mean for preventing respiratory collapse, which might prove of some value. One has, however, to bear in mind that warfare chemical agents, such as mustard gas, which can cause rapid exfo-

liation of the epithelial lining of the airways, or during inhalation of toxic fumes, little benefit is expected from the use of the biphasic extra-thoracic cuirass-based ventilation especially because of the rapid involvement of airway edema and the yet unproven efficacy of the device to prevent suffocation in such cases as opposed to the acceptable "gold standard" credit given to the ET.

We conclude that physicians wearing full antichemical protective gear can apply the cuirass and institute biphasic extra-thoracic ventilation faster than ET intubation. Further investigations are, however, warranted to provide answers to the limitations raised in this study, including optimal mode of air decontamination and possible means for oxygen supplementation without gas contamination, ventilation parameters, and different cuirass sizes availability for both adults and pediatric victims.

ACKNOWLEDGMENT

The authors thank Dr. Perla Eckstein for her intellectual and editorial input.

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