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Original Article

A commercial foot pump for emergency ventilation of horses, proof-of-principle during equine field anaesthesia

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Summary

At present there is no alternative to the use of a demand valve and pressurised oxygen for emergency ventilation in large animal field anaesthesia, therefore we aimed at providing a proof-of-principle of a small (2.5 l) commercial foot pump to provide emergency intermittent positive pressure ventilation (IPPV) in large animals. The study was performed during elective field anaesthesia for castration of 5 Haflinger stallions. Horses were premedicated with acepromazine i.m. after catheterisation of the jugular vein, further sedation was obtained with detomidine and butorphanol i.v. Anaesthesia was induced with ketamine and midazolam i.v. and maintained with a constant rate infusion of midazolam, ketamine and xylazine. After endotracheal intubation the foot pump, modified with a manually operated expiratory valve, was connected to the endotracheal tube and oxygen (6 l/min) was supplied. Anaesthesia was monitored using spirometry, respiratory gas analysis, pulse oximetry and arterial blood gas analysis. When arterial partial pressure of carbon dioxide ($PaCO_2$) exceeded 6.65 kPa, IPPV was provided by 2–4 consecutive compressions of the pump aiming at a tidal volume of 10 ml/kg bwt. The $PaCO_2$ was maintained at 6.18 ± 3.06 kPa (mean ± s.d.) with a respiratory rate of 4–10 breaths/min. The tidal volume was 2678–8300 ml with a peak inspiratory pressure of 24 ± 6.6 cmH_2O and a mean minute volume of 68.5 ± 13 l/min. Inspired oxygen concentration ranged from 26–46% (36 ± 7%) and arterial partial pressure of oxygen from 8.38–11.03 kPa (10.1 ± 0.93 kPa). The modified foot pump enables the practitioner to provide IPPV to large animals in emergency situations.

Introduction

Ventilatory support by means of application of intermittent positive pressure ventilation (IPPV) is universally accepted as a life-saving procedure in case of respiratory impairment or arrest and is a standard feature of cardiopulmonary resuscitation. This situation can occur in all species and conditions but represents a particular challenge for large animals and in field conditions. Guidelines for good anaesthetic practice suggest that as a minimum requirement every veterinarian should be able to perform IPPV manually by using a self-inflating bag or – in horses – a demand valve (AVA Committee Meeting Barcelona 2008).

In the early periods of human anaesthesia and resuscitation, emergency ventilation was provided with foot pump-like devices (i.e. Fell-O'Dwyer apparatus) (Trubuhovich 2009). In the 1950s a large (20 l) bellows-foot pump was used to perform artificial respiration in 12 horses (Rankin *et al*. 1952). Such large foot pumps were also incorporated in anaesthetic circle systems for horses (Schebitz 1955) or modified to become a manually operated stand-alone device (Überreiter 1958). A comparable device to the small foot pump used in this study has already been used in large animal emergencies when IPPV was needed, but its performance was not investigated in detail (H. Moerch, personal communication 2012).

The present study aims at providing a proof-of-principle of a small (2.5 l) commercial foot pump to provide emergency IPPV in large animals. The study was performed during field anaesthesia for castration of stallions.

Materials and methods

Description of the modified foot pump

A commercial 2.5 l foot pump (Bravo 7 M)[1] intended for the inflation of recreational items was used. The original pump consists of a bellows, an inlet valve and an exhaust valve allowing the venting of gas into an exhaust pipe. Modifications consisted of the addition of a custom made copper T-piece at the distal end of the exhaust pipe. This T-piece served as connector of the foot pump to endotracheal tubes of 25 or 30 mm inner diameter but was also designed to function as a manually operated expiratory valve. A rubber ball is pressed on the orifice (inner diameter of 30 mm) of the side port of the T-piece via an elastic rubber strap through its centre (**Fig 1**). The valve can be opened manually by rolling the ball to the side. When the bellows is compressed and the valve is in closed position, the device delivers a volume of 2.5 l with each step. When the valve is opened unobstructed expiration and also – if present – spontaneous breathing is possible. Furthermore the foot pump was provided with an inlet port for the provision of supplemental oxygen.

Animals

The Ethical Committee of the University of Veterinary Medicine Vienna approved the study. Five 2-year-old Haflinger stallions, with a bodyweight of 350 ± 15 kg were anaesthetised for field castration in lateral recumbency. Food, but not water was withheld for 12 h before anaesthesia.

Anaesthesia and monitoring

Each horse received 0.03 mg/kg bwt acepromazine (Vanastress)[2] i.m. prior to catheterisation of the jugular vein[3]. Further sedation was obtained with 0.015 mg/kg bwt detomidine (Medesedan)[4] and 0.02 mg/kg bwt butorphanol (Butomidor)[5] i.v. Anaesthesia was induced with 2.2 mg/kg bwt ketamine (Narketan 10%)[5] and 0.1 mg/kg bwt midazolam (Midazolam)[6] i.v. Orotracheal intubation was performed and anaesthesia maintained with an i.v. continuous rate infusion of

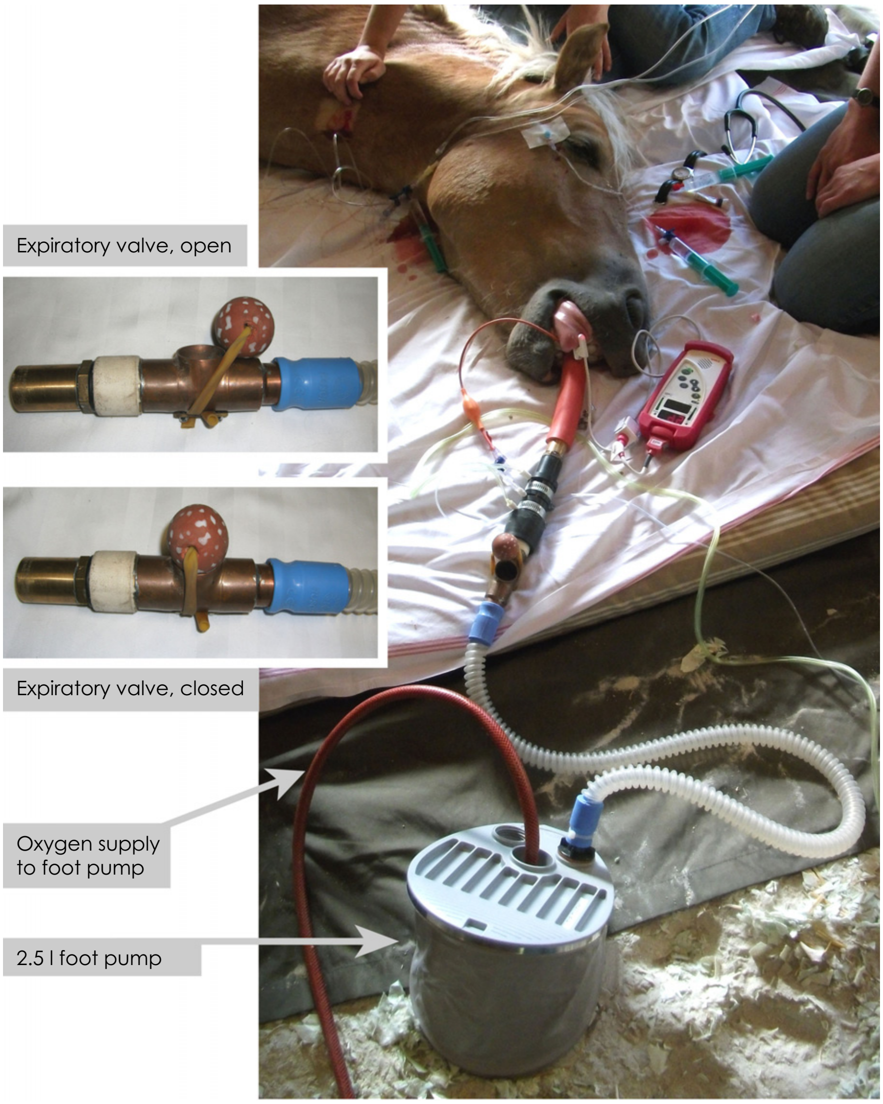

Fig 1: Setup for providing ventilatory support and oxygen with a modified foot pump during field anaesthesia.

midazolam (0.09 mg/kg bwt/h), ketamine (3.3 mg/kg bwt/h) and xylazine (Xylapan)[7] at 0.3 mg/kg bwt/h. During anaesthesia, i.v. lactated Ringer's solution[8] was administered at 10 ml/kg bwt/h. Horses were breathing ambient air supplemented with oxygen from a cylinder via insufflation into the endotracheal tube (spontaneous breathing) or into the inlet port on the foot pump (IPPV). For economic reasons a flow of 6 l/min was chosen. Anaesthesia was monitored clinically. Pulse rate assessed by palpation of the facial artery, respiratory rate and capillary refill time of the oral mucous membranes were recorded immediately after induction of anaesthesia and every 5 min throughout the anaesthesia period. Oxygen saturation was continuously measured using a hand-held pulse oximeter with the sensor clip on the tongue (Masimo Rad 5)[9]. Respiratory flow and volumes were measured using a pitot tube-based sensor for large animals (Horselite)[10] connected to the endotracheal tube. This sensor was connected to a dedicated monitor that performed respiratory gas analysis (Datex-Ohmeda Capnomac Ultima)[11]. The pressure-volume ('compliance') loops during IPPV shown on the screen display were recorded with a video printer (Mitsubishi Model P6 IE, Video Copy Processor)[12]. A catheter[13] was placed in a facial artery following induction. Arterial blood samples were drawn directly after catheter placement, 15 and 30 min after induction and at the end of anaesthesia. They were analysed immediately with a portable blood gas analyser (iSTAT Handheld Blood Analyzer)[14]. Horses were breathing spontaneously until blood gas analysis demonstrated hypercapnia (arterial partial pressure of carbon dioxide [$PaCO_2$] >6.65 kPa). Subsequently IPPV was provided by rapid consecutive compressions of the foot pump aiming to deliver a tidal volume of about 10 ml/kg bwt. The respiratory frequency was adjusted to maintain $PaCO_2$ below 6.65 kPa. Descriptive statistical data are given as mean ± s.d.

Results

Induction of anaesthesia was smooth and uneventful in all horses. Duration of anaesthesia was similar in all horses (44 ± 11 min). Four horses out of 5 became hypercapnic ($PaCO_2$ >6.65 kPa; 6.7 ± 0.41 kPa) within 15 min after induction of anaesthesia. With the foot pump, the lungs of these horses were inflated by 2–4 quick consecutive compressions of

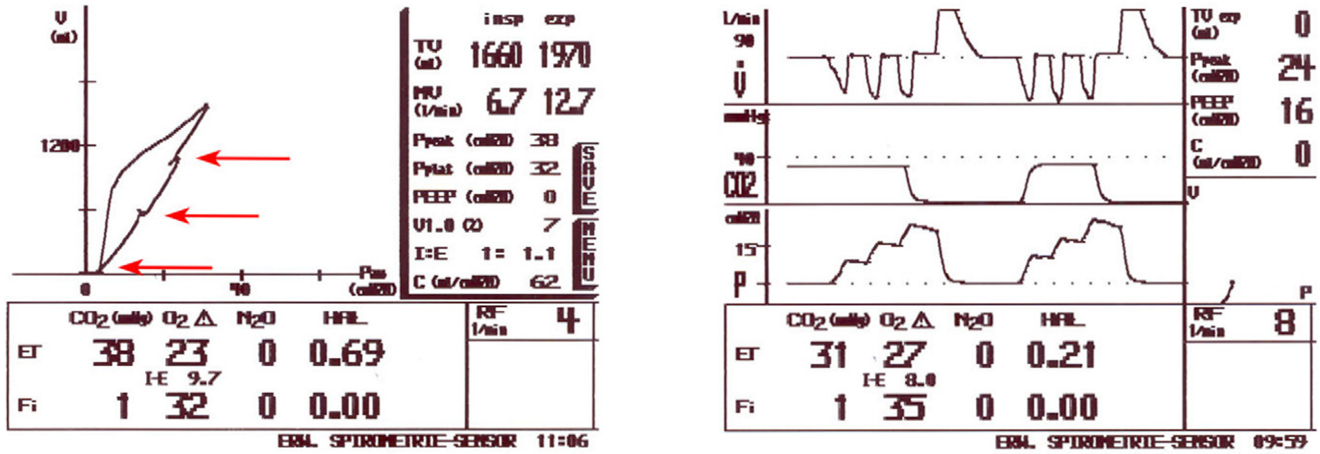

Fig 2: ***Videoprint of the display of the Datex Capnomac Ultima monitor showing pressure-volume loops, airway pressure and flow during intermittent positive pressure ventilation with a modified foot pump.***

the bellows followed by passive expiration via the manually opened valve. Spirometry and the pressure-volume loops showed that consecutive inflations were cumulative and provided tidal volumes that ranged from 2678 to 8300 ml (7.6–23.7 ml/kg bwt) (**Fig 2**). Four to 10 breaths/min (6.3 ± 1.9 breaths/min) were administered generating a mean peak inspiratory pressure of 24 ± 6.6 cmH_2O (17–39 cmH_2O), a mean minute volume of 68.5 ± 13 l/min and a mean $PaCO_2$ of 6.18 ± 3.06 kPa. Mild hypoxaemia developed in all ventilated horses despite an inspired oxygen concentration of 26–46% (36 ± 7%). The arterial partial pressure of oxygen (PaO_2) ranged from 8.38–11.03 kPa (10.1 ± 0.93 kPa). Recovery from anaesthesia was uneventful in all cases.

Discussion

This study demonstrated that it is possible to generate a sufficient tidal volume, minute volume and peak inspiratory pressure to maintain $PaCO_2$ within clinically acceptable values for anaesthetised intubated horses using a modified foot pump as an emergency ventilator. This is possible with quick consecutive compressions of the bellows whereby the short filling time constant of the pump and relatively long expiratory time constants of the equine lung lead to accumulation of insufflated volumes as illustrated in the pressure-volume loops of **Figure 2**. Although the target tidal volume was 10 ml/kg bwt, it proved possible in a short-term trial during this study to generate higher volumes (up to 23.7 ml/kg bwt) with a peak inspiratory pressure of up to 39 cm H_2O by increasing the number of successive compressions. This proves that although only horses of about 350 kg bodyweight were used in this study, larger tidal volumes can be realised (up to 8 l), sufficient to ventilate larger horses in emergency situations (unpublished data).

Foot pump-type emergency devices to provide IPPV to large animals in field conditions have not been recently described, and older ones are not available anymore and were probably too bulky to be practical (Rankin *et al*. 1952). This modified foot pump is a cheap, lightweight device and easily transported and connected to an endotracheal tube. The use of the pump as an emergency ventilator (opening and closing the valve by rolling the ball aside) is easy to understand and also untrained assistants are able to take over mechanical ventilation within short notice. The operator must be aware of safety issues when using the device. First, there is no airway pressure indication and thus no warning for excessively high airway pressure. Airway pressure release will also depend on the tension of the rubber fixation and can be increased when the operator exerts manual pressure on the valve ball during inspiration. Second, the operator needs to keep an eye on the presence of spontaneous respiratory efforts. In this case it is mandatory to assure an open valve position if negative airway pressures with the risk of subsequent negative pressure pulmonary oedema are to be avoided. This can occur when the horse tries to breath from the limited volume of the foot pump. During emergency ventilation ideally inspired air should be enriched with oxygen and this modified foot pump can be used with or without oxygen supplementation. Impaired oxygenation due to V/Q mismatch and hypoventilation can be partially treated by increasing fraction of inspired oxygen (Marntell *et al*. 2005). In this study, IPPV provided with the foot pump yielded clinically acceptable $PaCO_2$ levels, although higher levels (>6.65 kPa) could certainly be tolerated; this should allow a practitioner to provide sufficient IPPV in emergency or resuscitation situations until spontaneous respiration resumes. It is noteworthy that mechanical ventilation with the foot pump corrected hypercapnia in all horses in the present study but could not prevent hypoxaemia.

Alternatively to a foot pump a demand valve can be used to provide IPPV and oxygen to intubated horses. Although application of oxygen is a major advantage with the demand valve there are also some drawbacks. A disadvantage is the need for a transportable pressurised gas source and the need for high oxygen flows (40–275 l/min) to operate the device (Hartsfield 2007). The oxygen flow needed to enrich inspired air in horses is much lower (up to 15 l/min) than the flow needed to operate the demand valve and hence longer operational times are possible for example a 2 l oxygen cylinder will last <10 min. Furthermore, transport of oxygen cylinders in a car carries a health and safety risk and is regulated by law in Europe.

Conclusion

The modified foot pump is a cheap and lightweight device that enables the practitioner to provide IPPV to large animals in emergency situations as suggested by the guidelines for good anaesthetic practice. The procedure is easy to understand and also untrained assistants are able to take over mechanical ventilation within short notice.

Authors' declaration of interests

No conflicts of interest have been declared.

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Manufacturers' addresses

[1]Boarder-Stuff Outdoor, Amtzell, Germany.
[2]Vana GmbH, Vienna, Austria.
[3]Laboratoires Pharmaceutique Vygon, Écouen, France.
[4]Virbac GmBH, Vienna, Austria.
[5]Vetoquinol Austria GmbH, Vienna, Austria.
[6]Mayrhofer Pharmazeutika, Linz, Austria.
[7]Vetoquinol AG, Ittigen, Switzerland.
[8]Fresenius Kabi Austria GmBH, Linz, Austria.
[9]Massimo Corporation, Irvine, California, USA.
[10]Morpheus Engineering, Wenum Wiesel, Netherlands.
[11]Datex Ohmeda Instrumentarium Corp., Helsinki, Finland.
[12]Mitsubishi Electric Europe B.V., Visual Information Systems, Ratingen, Germany.
[13]Terumo Europe N.V., Leuven, Belgium.
[14]Abbott Laboratories, Abbott Park, Illinois, USA.

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