HORSES AND OTHER EQUIDS

# Inadvertent activation of a PEEP valve leading to potentially severe cardiopulmonary complications in a horse

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## SUMMARY

A five-year-old Austrian thoroughbred mare underwent anaesthesia and was mechanically ventilated using a Smith respirator L.A.-90. Shortly after commencing, capnography displayed a curve compatible with airway obstruction and haemoglobin saturation decreased progressively. Unexpectedly, positive-end expiratory pressure and peak inspiratory pressure reached 20 cm $H_2O$ and 50 cm $H_2O$, respectively. The ventilator was disconnected and the patient ventilated manually, promptly correcting capnography and saturation. A later inspection of the ventilator identified two problems. The expiratory flow regulator, made of two overriding metal rings, was inadvertently rotated, preventing gas from escaping the system during expiration. Additionally, the poorly labelled knob limiting PIP had been left on 50 cm $H_2O$. The authors describe a critical incident due to both, some specific features and limitations of the Smith Respirator L.A.-90, and the lack of familiarity of the anaesthetists with the ventilator. Implementing checklists may guide inexperienced users through the safe use of equipment.

## BACKGROUND

Adverse events are described to occur in any field of medicine leading to a variety of consequences for patient outcome (Amucheazi and Ajuzieogu 2010), from transient damage to increased length of hospital stay and, in the worst scenario, rise of permanent illness or patients' death (Manghnani and others 2004). Anaesthesia is the fulcrum of the interaction between several disciplines. An anaesthetist is in constant communication with relevant numbers of colleagues, nurses, technicians and patients (or, in veterinary medicine, patient's owners), and working with complex machines and multivariable environments. Therefore the risk of adverse events in this area of medicine is particularly important to be recognised and reduced (Blum 1971).

Based on this peculiarity, the role of the anaesthetist has been frequently compared with that of persons working in other high-risk systems, such as aviation (Gupta and others 2009). In 1978, in fact, Cooper and others described that in anaesthesia the most frequent cause of problems is human error and introduced the concept of recording critical incidents as already performed in aviation psychology in the US Air Force during and after World War II (Manghnani and others 2004). Incident reporting systems have been a key tool to improve safety and enhance organisational learning from incidents (Mahajan 2010). Every time an incident occurs, a report should be produced and used as a basis for training, simulation and improvement in standard of anaesthesia care (Vincent 2004). Furthermore, the possibility to share and discuss critical incidents plays a major role in preventing recurrences (van der Schaaf 2002) as it provides a clearer understanding of the process leading to the accident (Mahajan 2010).

Taking the abovementioned background into account, the present case report describes a human error by which the development of a capnography reading compatible with airway obstruction has been achieved in a horse undergoing head CT due to inadvertent dislodgment of the Smith ventilator expiratory flow regulator and the creation of an unwanted auto-positive end-expiratory pressure (PEEP).

## CASE PRESENTATION

A five-year-old Austrian thoroughbred mare was admitted for CT of the head to diagnose dental disease. The patient was judged healthy on the base of a normal clinical examination and results of blood work. The horse received acepromazine (0.03 mg/kg; Vetranquil, Ceva Tiergesundheit GmbH, Germany) intramuscularly 25 min before induction. It was premedicated with xylazine (0.6 mg/kg; Rompun, Bayer Austria, Austria) and butorphanol (0.04 mg/kg; Alvegesic, Alvetra WERFFT, Germany) intravenously. Anaesthesia was induced intravenously with midazolam (0.1 mg/kg; Bad Ischl Apotheke, Austria) followed by ketamine (2.2 mg/kg; Narketan, Vetoquinol, Austria). As the anaesthetic plane was judged too superficial, the horse received a bolus of 10 ml of 2.5% thiopental (Thiopental, Sandoz, Austria) before intubation. The trachea was then intubated with a 26 mm cuffed silicone endotracheal tube. The horse was lifted to the table, positioned in dorsal recumbency, connected to a large animal breathing system and instrumented. After the thiopental bolus the horse presented apnoea. Mechanical ventilation was therefore started immediately using a Smith respirator L.A. 90 (Smith, Denmark) set to deliver 6 breaths/min with a tidal volume of 5 Litres. Monitoring included pulse oximetry ($SpO_2$), capnography and ECG. Evaluation of palpebral reflexes, mucous membrane colour, capillary refill time and pulse quality was realised between the sequences when access to the horse was granted.

After 15 min of mechanical ventilation, the capnography displayed a curve compatible with airway obstruction depicted as an increase of the α angle and a steeper slope of the alveolar plateau with the length of the alveolar plateau progressively shortening. The visible part of the endotracheal tube was inspected for cause of obstruction. Cuff herniation was excluded by deflating the cuff, moving the endotracheal tube and re-inflating the cuff. Manometer readings on the ventilator and the anaesthetic machine, as well as bellow movement, were checked. The $SpO_2$ reading, initially on 99%, rapidly decreased in the next 5 min reaching the lowest point of 78% at the moment the anaesthetists were able to enter the room. The horse's vital signs were examined. A weak pulse was palpated at the facial artery, mucous membrane colour was pale and capillary refill time was prolonged. Arterial blood was drawn from the facial artery for arterial blood gas analysis. Ipratropium bromide (3 $\mu$g/kg) was administered via the capnography port of the Y-piece of the breathing circuit, as no obvious problem had been previously identified on the ventilator side. Shortly after, it was noted that the bellow of the ventilator did not realise the full movement of 5 Litres and the manometers of the respirator and the breathing system were showing a PEEP of 20 $cmH_20$ and a peak inspiratory pressure (PIP) of 50 $cm H_2O$ per mechanical ventilation. The horse was immediately disconnected from the ventilator and ventilated manually instead at a PIP of 20 $cm H_2O$ and a respiratory rate (FR) of 4–6 breaths/min. The capnography curve returned to a normal shape and the $SpO_2$ reading increased to 94% within 5 min. Blood gas analysis results became available once the respiratory parameters had returned to normal and revealed a partial pressure of oxygen ($PaO_2$) of 430.4 mm Hg and a partial pressure of carbon dioxide ($PaCO_2$) of 59.7 mm Hg. The rest of anaesthesia was uneventful. The total duration of anaesthesia was 50 min. Oxygen (15 L/min) was insufflated via the nostrils for 15 min during recovery. Recovery was unassisted and uneventful. The horse stood on the first attempt 22 min after the end of anaesthesia and showed mild ataxia.

After the accident, another anaesthetist inspected the ventilator closely. Two problems were identified. The ventilator is provided with an expiratory flow regulator, consisting of two steel rings with orifices sliding one over the other. By adjusting the external ring, the orifices can be progressively opened or closed in order to regulate the amount of flow escaping to the scavenging system during expiration (Fig 1). It was discovered that the outer ring was partially occluding the orifices (Figs 2 and 3). Additionally, the PIP-limiting knob had been left on 50 $cm H_2O$ from a previous user (Fig 4).

**FIG 1:** Expiratory flow regulator with semi-closed orifices.

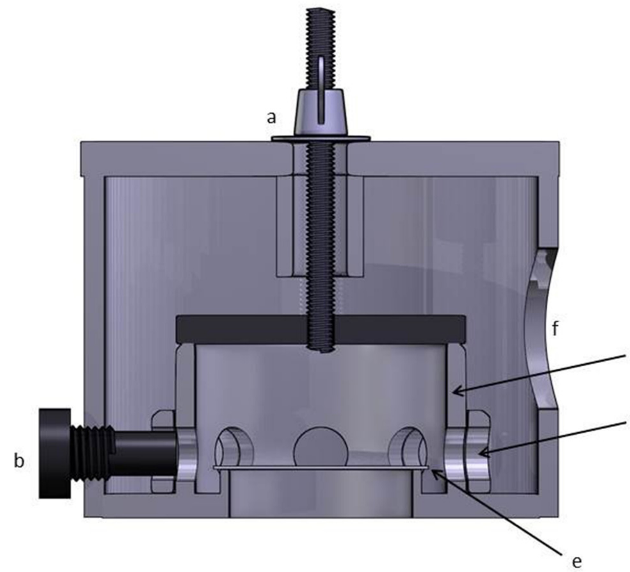


**FIG 2:** Diagram depicting a transversal cut section of the expiratory valve of the Smith L.A.-90 ventilator. (a) Acrylic cup holding screw (b) Plastic screw fixating the steel rings with orifices, (c) Inner ring of the steel rings with orifices, (d) Outer ring of the steel rings with orifices, (e) Unidirectional valve disc (not depicted in figure 3 to facilitate visualisation of gas flow), (f): Connection to active gas scavenging system

## DISCUSSION

When problems occur during anaesthesia, it is most commonly due to the misuse of equipment, an error by the anaesthetist or equipment failing while the user is unaware that a failure has occurred (Eisenkraft 2004). Critical incidents are defined as incidents that (1) could have led, if not discovered or corrected in time, or did lead, to an undesirable outcome; (2) involved an error by a member of the anaesthesia team or a failure of the

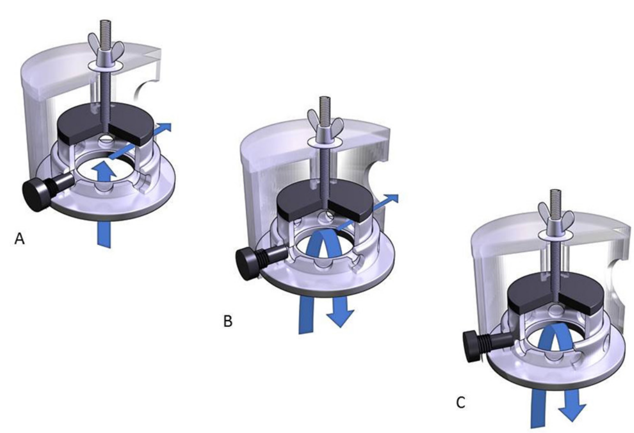


**FIG 3:** Three-dimensional model of the expiratory valve of the Smith L.A.-90 ventilator. (A) The steel rings with orifices are open. Gas is scavenged to the AGSS. (B) The steel ring orifices are partially obstructed. Gas only partially escapes to the AGSS. Remaining gas flow is reflected towards the patient, increasing the end-expiratory pressure. Increasing PEEP depends on the degree of orifice closure. (C) The steel ring orifices are completely obstructed. Gas flow is completely redirected towards the patient causing an increase in end-expiratory pressure. Auto-PEEP is generated and severely endangers the patient. AGSS, active gas scavenging system; PEEP, positive end-expiratory pressure


**FIG 4:** Peak inspiratory pressure-limiting device.

anaesthesiologist's equipment to function properly; (3) occurred during patient care; (4) could be clearly described; and (5) were clearly preventable (Cooper and others 1978). The importance of reporting them has become more and more recognised. The present report describes such a critical incident due to failure of the anaesthetists to recognise an inadvertently half-closed expiratory flow regulator of a Smith Respirator L.A. 90, which may have created an auto-PEEP.

Severe airflow obstruction is a common cause of acute respiratory failure. Dynamic hyperinflation affects tidal ventilation, increases airways resistance and causes an undesired PEEP (Moens and others 1998). PEEP is defined as an above atmospheric pressure in the alveoli by the end of expiration and has been commonly used intentionally in horses to prevent collapse of alveoli and increase functional residual capacity (Blanch and others 2005, Wettstein 2006, Schürmann 2008, Bringewatt and others 2010, Hopster and others 2011, Ambrósio and others 2013). However, if PEEP arises inadvertently, it is called intrinsic PEEP or auto-PEEP and can have severe cardiopulmonary consequences.

The development of auto-PEEP in horses has been described in a single case report by Gregson and Clutton (2012), when the misuse of medical tape around the endotracheal tube connector resulted in development of a functional one-way valve, allowing inspiration but impairing expiration. The clinical signs these authors observed were hypoxaemia that was deteriorating over time and a notably distended abdomen and thorax, which seemed to deflate when the endotracheal tube was disconnected from the breathing system. They did not comment on the shape of the capnogram. Instead, in the present case the first sign the authors noticed was a change in the capnogram consisting of a prolongation of the expiratory upstroke ('shark-fin') indicative of bronchospasm or partial expiratory obstruction (D'Mello and Butani 2002). The endotracheal tube was examined for obstructive cuff herniation, as has been described in dogs (Bergadano and others 2004). Since no obvious reasons for an endotracheal tube obstruction were detected, bronchospasm was suspected and treated with ipratropium bromide. When no improvement in capnography or $SpO_2$ readings occurred within the next few minutes, additional causes were sought. At this time the attending anaesthetists noticed an incomplete movement of the bellow. The manometer was read and dangerously high PIP and PEEP were identified. Since the ventilator was suspected to be the cause of the problem, it was immediately disconnected and manual ventilation resumed. This resulted in progressive improvement of the oxygen saturation.

Although PEEP is commonly used to prevent or treat hypoxaemia in horses, it may also have the opposite effect. If PIP and PEEP are insufficient to reopen collapsed lung areas, or, on the contrary, extensively high, the increases in regional volume caused by PEEP are distributed to already well ventilated lung regions, thereby causing a further expansion of ventilated alveoli (Bindslev and others 1981) and in turn their overinflation. Additionally, Brandolese and others (1993) found that while both PEEP and auto-PEEP decreased cardiac output, arterial oxygen tension was lower in patients with auto-PEEP than in patients with a comparable level of external PEEP, an effect the authors attributed to a less homogeneous distribution of auto-PEEP among lung units. Interestingly, in the present case the authors discovered a high $PaO_2$ once blood gases became available despite the low measured $SpO_2$. The authors therefore suspect that this low $SpO_2$ may have been an artefact due to inadequate peripheral perfusion rather than actual hypoxaemia. It has been shown that the application of PEEP will lead to an increase in intrathoracic pressure which in turn will affect left ventricular preload, afterload and contractility (Hodgson and others 1986). Pinsky and others (1992) showed that stepwise PEEP-titration was coupled with a linear pressure-dependent decrease in cardiac index and mean arterial pressure. Several other authors have also described these detrimental effects in horses (Steffey and others 1992, Mizuno 1994, Edner and others 2005, Hopster and others (2011)). According to the manometer, a PIP of 50 cm $H_2O$ was reached with every breath. Wilson and others (1990) showed an almost 50% decrease in cardiac output and tissue oxygen delivery from baseline with application of a 30 cm $H_2O$ PEEP. Hopster and others (2011) observed a decrease in cardiac index to less than 30 mL/kg/min and in mean arterial pressure to below 40 mm Hg with a PIP of 45 cm $H_2O$ and a PEEP of 25 cm $H_2O$. These pressures are comparable with the pressures observed in the present case and a similar effect on cardiovascular parameters can be expected. Unfortunately blood pressure measurement was not available in CT and the authors had to rely on subjective digital evaluation of the pulse strength. Pulses were considered weak, mucous membranes very pale and capillary refill time was prolonged, supporting the authors' suspicion of impaired cardiac output due to impaired venous return by the high intrathoracic pressures. However, these findings have to be interpreted with caution, since the horse had received an $\alpha_2$-agonist before induction of anaesthesia. The resultant expected vasoconstriction may have resulted in a similar clinical presentation, causing poor peripheral perfusion.

Data observed on the capnogram was accurate and allowed the anaesthetists to diagnose an obstructive problem, either caused by airway obstruction or bronchospasm, correctly. The anaesthetists undertook a series of logical steps, which allowed recognition of a critical incidence before harm was inflicted on the patient. Nevertheless, it is probable that if the anaesthetists had been aware of the specific features of the Smith respirator, particularly the potential for expiratory flow regulator dysfunction, they would have placed it higher on the list of possible causes inducing the problem at hand. The time until resolution of the problem may therefore have been decreased.

In this case report the underlying problem was identified early enough to prevent serious injury in this animal, however, if undetected, cases like this one may lead to a fatal outcome. A chain of several technical and human failures led to the occurrence of the problem encountered by the authors. The most important factor was the inexperience of the attending anaesthetists with the Smith Respirator and the unfamiliarity with some of its unique features. The Association of Anaesthetists of Great Britain and Ireland published a 'checklist for anaesthetic equipment' where they stress the importance of familiarity with equipment in use and the need for a formal introduction to these machines. This did not happen in the present case. Therefore the anaesthetists were not aware of the design and position of the expiratory flow regulator and the pressure-limiting device. The expiratory flow regulator device can be used to change expiratory flow time by altering the diameter of the expiratory orifice (Fig 1). Unless a very specific setting of the ventilator parameters is required, it should be completely open when using mechanical ventilation. As the anaesthetists were not aware of this special feature of the ventilator, it was not verified before use. As the problem developed over a relatively large time span, the authors suspect that the orifices were open at the beginning of ventilation, but the position of the outer ring of the expiratory flow regulator was accidently modified during anaesthesia. This normally should be prevented by a nylon screw fixating the outer ring over the inner ring. After the accident had occurred, the authors detected that this security feature was inadequate as despite maximal tightening of the screw the outer ring was easily movable over the inner ring. Another safety feature exists in the form of a pressure-limiting device. This device interrupts the inspiratory phase and shifts the system to the expiratory phase when the pressure in the system exceeds the limit preset by the anaesthetist. When used correctly it can protect the patient from pulmonary overinflation. Once again the anaesthetists were not aware of the presence of this feature and did not preset the pressure limit appropriately. Nonetheless this safety feature is also inadequate as it is not clearly labelled and as the ventilator does not give visual or auditory alarms when abnormally high inspiratory pressures are reached. Therefore, the anaesthetists, who could not remain next to the patient during the CT scan, became aware of the problem very tardive.

The second factor was the lack of a complete preanaesthetic equipment check. Although a leak test of the anaesthetic machine was performed before anaesthesia, the ventilator was not tested. Therefore, the attending anaesthetists did not realise that the maximum PIP limit was set at 50 cm$H_2O$ when the tidal volume was set and the volume-controlled mechanical ventilation started. This made the occurrence of the observed high PIP possible. In human medicine it has been accepted that a substantive portion of the anaesthetic risk is related to errors in management or deviations from accepted practice (Goldstein and Keats 1970) and the *Journal of Health Devices* listed anaesthesia hazards due to incomplete preuse inspection as one of the top 10 technology hazards in 2012. The use of a safety checklist could have avoided this incident and should be implemented as a routine procedure before anaesthesia, as has been recommended by WHO.

Checklists have been used both in medical and non-medical fields and have proven to be one of the best instruments to improve safety especially when implemented in high-intensity fields like aviation and anaesthesia (Fasting and Gisvold 2002, Hales and others 2008, Toff 2010). A leak test was realised before anaesthesia, but the leak test was not adequate to identify this problem. A stepwise checklist leading the anaesthetist through the settings of the machine, despite of lack of time to form him, could have prevented this incident from happening.

In conclusion, this case report describes a chain of events generated by a combination of human error, specific features and poorly conceived safety mechanism of the Smith respirator L.A. 90, potentially leading to severe cardiorespiratory complication in a horse. The authors want to alert practitioners working with the Smith respirator of the importance to check the expiratory flow regulator and the pressure-limiting device settings before use. Additionally, it highlights the utility of implementing checklists, which may guide inexperienced users through the safe use of equipment.

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## REFERENCES

Ambrósio A. M., Ida K. K., Souto M. T., Oshiro A. H., Fantoni D. T. (2013) Effects of positive end-expiratory pressure titration on gas exchange, respiratory mechanics and hemodynamics in anesthetized horses. *Veterinary Anaesthesia and Analgesia* 40, 564–572

Amucheazi A. O., Ajuzieogu O. V. (2010) Critical incidents during anesthesia in a developing country: A retrospective audit. *Anesthesia: Essays and Researches* 4, 64–68

Bergadano A., Moens Y., Schatzmann U. (2004) Two cases of intraoperative herniation of the endotracheal tube cuff. *Schweizer Archiv für Tierheilkunde* 146, 565–569

Bindslev L., Santesson J., Hedenstierna G. (1981) Distribution of inspired gas to each lung in anesthetized human subjects. *Acta Anaesthesiologica Scandinavica* 25, 297–302

Blanch L., Bernabé F., Lucangelo U. (2005) Measurement of air trapping, intrinsic positive end-expiratory pressure, and dynamic hyperinflation in mechanically ventilated patients. *Respiratory care* 50, 110–124

Blum L. L. (1971) Equipment design and "Human" Limitations. *Anesthesiology* 35, 101–102

Bringewatt T., Hopster K., Kästner S. B., Rohn K., Ohnesorge B. (2010) Influence of modified open lung concept ventilation on the cardiovascular and pulmonary function of horses during total intravenous anaesthesia. *Veterinary Record* 167, 1002–1006

Cooper J. B., Newbower R. S., Long C. D., McPeek B. (1978) Preventable anesthesia mishaps: a study of human factors. *Anesthesiology* 49, 399–406

D'Mello J., Butani M. (2002) Dr. Jacqueline D'Mello 1 Dr. Manju Butani 2. *Indian Journal of Anaesthesia* 46, 269–278

Edner A., Nyman G., Essén-Gustavsson B. (2005) The effects of spontaneous and mechanical ventilation on central cardiovascular function and peripheral perfusion during isoflurane anaesthesia in horses. *Veterinary Anaesthesia and Analgesia* 32, 136–146

Eisenkraft J. (2004) Hazards of anesthesia gas delivery systems. *Canadian Journal of Anesthesia/Journal canadien d'anesthésie* 51, R26–R31

Fasting S., Gisvold S. E. (2002) Equipment problems during anaesthesia--are they a quality problem? *British Journal of Anaesthesia* 89, 825–831

Goldstein A., Keats A. S. (1970) The risk of anesthesia. *Anesthesiology* 33, 130–143

Gupta S., Naithani U., Brajesh S. K., Pathania V. S., Gupta A. (2009) Critical incident reporting in anaesthesia: a prospective internal audit. *Indian journal of anaesthesia* 53, 425–433

Hales B., Terblanche M., Fowler R., Sibbald W. (2008) Development of medical checklists for improved quality of patient care. *International Journal for Quality in Health Care* 20, 22–30

Hodgson D. S., Steffey E. P., Grandy J. L., Woliner M. J. (1986) Effects of spontaneous, assisted, and controlled ventilatory modes in halothane-anesthetized geldings. *American Journal of Veterinary Research* 47, 992–996

Hopster K., Kästner S. B., Rohn K., Ohnesorge B. (2011) Intermittent positive pressure ventilation with constant positive end-expiratory pressure and alveolar recruitment manoeuvre during inhalation anaesthesia in horses undergoing surgery for Colic, and its influence on the early recovery period. *Veterinary Anaesthesia and Analgesia* 38, 169–177

Mahajan R. P. (2010) Critical incident reporting and learning. *British Journal of Anaesthesia* 105, 69–75

Manghnani P. K., Shinde V. S., Chaudhari L. S. (2004) Critical incidences during anaesthesia "an Audit". *Indian Journal of Anaesthesia* 48, 287–294

Mizuno Y. (1994) Cardiovascular effects of intermittent positive pressure ventilation in the anesthetized horse. 56, 39–44

Moens Y., Lagerweij E., Gootjes P., Poortman J. (1998) Influence of tidal volume and positive end-expiratory pressure on inspiratory gas distribution and gas exchange during mechanical ventilation in horses positioned in lateral recumbency. *American Journal of Veterinary Research* 59, 307–312

Pinsky M. R., Desmet J. M., Vincent J. L. (1992) Effect of positive end-expiratory pressure on right ventricular function in humans. *American Review of Respiratory Disease* 146, 681–687

Schürmann P. (2008) Optimierung des pulmonalen gasaustausches während der pferdenarkose durch beatmung nach dem "Open Lung Concept". *Pferdeheilkunde*. 24, 236–242

Steffey E. P., Willits N., Woliner M. (1992) Hemodynamic and respiratory responses to variable arterial partial pressure of oxygen in halothane-anesthetized horses during spontaneous and controlled ventilation. *American Journal of Veterinary Research* 53, 1850–1858

Toff N. J. (2010) Human factors in anaesthesia: lessons from aviation. *British Journal of Anaesthesia* 105, 21–25

Vincent C. A. (2004) Analysis of clinical incidents: a window on the system not a search for root causes. *Quality and Safety in Health Care* 13, 242–243

van der Schaaf T. W. (2002) Medical applications of industrial safety science. *Quality and Safety in Health Care* 11, 205–206

Wettstein D. (2006) Hemodynamic and pulmonary consequences of an alveolar recruitment manoeuvre during total intravenous anaesthesia in shetland ponies. *American Journal of Veterinary Research* 67, 152–159