Two cases of intraoperative herniation of the endotracheal tube cuff

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Summary

During anaesthesia for elective procedures, 2 dogs developed acute airway obstruction caused by herniation of the endotracheal cuff. This is an uncommon but potentially fatal complication especially when minimal monitoring of the patient leads to late recognition of the condition. The most typical symptoms are decreased thoracic excursions and tidal volume, absence of gas flow through the endotracheal tube, change in the capnographic waves morphology and increased airway pressures. In both cases desaturation of haemoglobin (measured by pulse oximetry) occurred in-between 6 and 8 minutes after cuff herniation. All signs normalised following partial deflation of the cuff. Careful management of cuff pressures especially when nitrous oxide is used, awareness of the condition and monitoring of the patient can prevent fatal consequences.

Keywords: cuff hernia, nitrous oxide, tidal volume, capnography, volume/pressure loops

Zusammenfassung

Während eine Allgemeinanästhesie haben 2 Hunde eine akute Atemwegeobstruktion durch eine Tubusmanchettenhernie entwickelt, ein seltener Zwischenfall, der zum Tod führen kann falls die Ursache nicht erkannt wird. Auffällige Kennzeichen sind: eine eingeschränkte Thoraxbewegung, ein erniedrigtes Atemzugvolumen, eine Änderung in die Kapnographiekurvenmorphologie und erhöhter Atemwegsdruck. Die Sauerstoffsättigung war in beiden Fallen ein ungenügend Monitoringparameter. Die Symptome haben sich nach dem Ablassen von Luft aus der Tubusmanchette sofort normalisiert. Die Gefahr eine Herniebildung mit Blockierung der Atemwege ist besonderes bei Verbrauch von Lachgas und Silikontubussen pendent. Probleme lassen sich durch die Messung und Kontrolle des Manschettedrucks (nicht über 30 mmHg) weitgehend verhindern.

Schlüsselwörter: Tubusmanchettenhernie, Lachgas, Atemzugvolumen, Kapnographie, Druck/Volumen Kurven

Introduction

The intra-operative enlargement with herniation of the endotracheal (ET) tube cuff is a rare event. The consequences of this condition may be life threatening (Bar-Lavie et al., 1995) as it impairs ventilation during anaesthesia. Possible causative factors are use of nitrous oxide, accidental overinflation of the cuff and cuff material. We report two cases of cuff herniation which occurred during anaesthesia for elective procedures.

Case 1

A 10 months old male bernese shepherd dog, weighing 39 kg was scheduled for a right elbow arthroscopy. The dog was pre-medicated with 0.02 mg kg^{-1} acetylpromazine (Prequillan; Fatro, Ozzano Emilia, I) and 0.12 mg kg^{-1} methadone (Graeub AG, Bern, CH) intramuscularly (IM). An 18G catheter was placed in the left cephalic vein. Induction was performed with intravenous (IV) propofol 2.5 mg kg^{-1} (Propofol 1%; Fresenius Kabi AG, Bad Homburg, DE) and the trachea was intubated with a 14 mm ID ET tube, high pressure/low volume cuff with Murphy-eye design (Aire-cuf; Bivona Inc., Gary, ID, USA). The cuff was inflated with room air to obtain a leak proof seal, checked by auscultation. Anaesthesia was maintained with isoflurane (Isoflo® ad us. vet., Abbot AG, Baar, CH) carried by a oxygen/nitrous oxide mixture (O_2/

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N_2O; $FIO_2 = 0.4$) delivered using a semi-closed circle system. Fentanyl (Fentanyl-Curamed i.v.; curaMED Pharma GmnH, Karlsruhe, DE) was infused IV at 4 μg kg^{-1} h^{-1} for intraoperative analgesia. Monitoring (Infinity Series SC 7000, Siemens) consisted in electrocardiography (ECG), pulse oximetry (SpO_2), non-invasive blood pressure, respiratory gases, anaesthetic agent concentration and spirometry. The lungs were mechanically ventilated (Kion System, Servo-ventilator 300, Siemens-Elma Electromedical Systems Division, Solna, SW) in volume-control mode, with a respiratory frequency (RF) of 15 breaths min^{-1} and a tidal volume (TV) of 400 ml to reach normocapnia. The peak inspiratory pressure (PIP) was 10 cm H_2O and the high airway pressure limit of the ventilator was set at 20 cm H_2O.

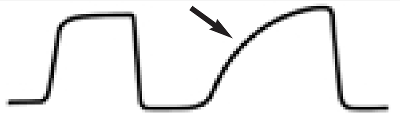

Figure 1: Schematic representation of a normal capnogram (left) and in case of airway obstruction (right). The slope of the expiratory phase is increased, "slurring" (arrow).

While the dog was positioned for surgery (min 49 of anaesthesia) abrupt changes in the monitored ventilatory parameters occurred: the capnographic waveforms showed a slurred expiratory phase (Fig.1), the TV decreased to 194 ml, PIP increased over the airway high pressure limit of 20 cm H_2O and the pressure/volume loops (P/V) were flattened and shifted to the right, suggesting a decrease in lung compliance (Fig. 2). The change in thoracic compliance was interpreted as a consequence of the positioning for the arthroscopy. The ventilation mode was changed to "pressure controlled" with a PIP set at 10 mmHg (min 51). This resulted in a further decrease in TV. Heart rate (HR: 76 min^{-1}), saturation of oxygen measured by pulse oximetry ($SpO_2 = 98\%$), $ETCO_2$ (40 mmHg) and clinical signs of depth of anaesthesia were still judged satisfactory. At min 57, PIP raised again above the airway high pressure limit, accompanied by a decrease in SpO_2 (87%), $ETCO_2$ (11 mmHg) and tachycardia occurred (134 min^{-1}). Clinically, thoracic excursions were reduced, attempts to ventilate the dog manually were barely possible and only by generating very high inspiratory pressures, therefore a presumptive diagnose of airway obstruction was done. The dog was disconnected from the machine to allow inspection of tube location and patency, and it was noticed that no gas was coming out of the tube. Subsequently the cuff was deflated with the intention to replace the ET tube, however following its partial deflation all the signs resolved quickly: air flow through the tube and thorax excursions resumed. This was followed by a quick normalisation of TV (406 ml), HR (84 min^{-1}), SpO_2 (98%) and the dog was shortly hyperventilated to decrease $ETCO_2$ from 47 to 40 mmHg. At min 58 N_2O was withdrawn and anaesthesia proceeded uneventfully as well as recovery.

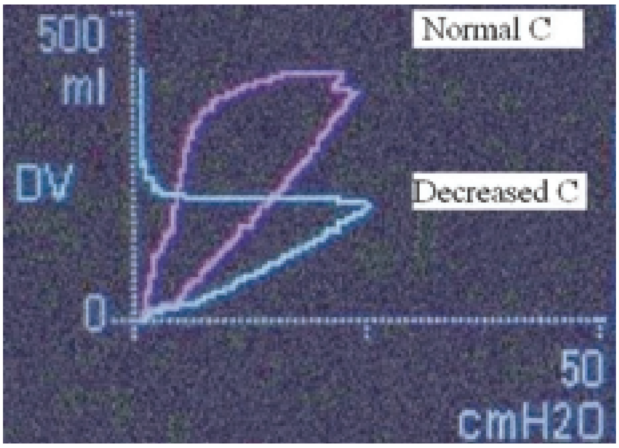

Figure 2: Change occurred in the pressure /volume (P/V) loop during cuff herniation: there is a flattening of the P/V loop indicating decreased compliance. x axis: airway pressure (P), y axis: tidal volume (V), compliance (C)

Case 2

A 2 year old male napolitan mastiff, weighing 70 kg was scheduled for a cruciated ligament repair. He was premedicated with 14 mg kg^{-1} medetomidine IM (Domitor; Orion Corporation, Espoo, Finland) and anaesthesia was induced with 1.5 mg kg^{-1} IV propofol. The trachea was intubated with a 14 mm ID cuffed silicone ET tube and anaesthesia maintained with isoflurane in O2 ($FIO_2 = 1$). The lungs were mechanically ventilated in volume-control mode to normocapnia with a RF of 10 min^{-1} and TV of 550 ml. An epidural injection of local anaesthetic was given for hind limb analgesia. Anaesthesia was uneventful for 250 min. Before moving the patient for postoperative x-rays, the cuff was reinflated by the technician without checking its pressure. At min 256, the monitored TV and the $ETCO_2$ suddenly decreased to zero, while SpO_2 decreased from 95% to 63% only 6 minutes after airway obstruction. The cuff was subsequently partially deflated and ventilation normalised quickly. The remaining 30 min of anaesthesia and recovery were uneventful. This episode happened two days after case 1.

In vitro reconstruction

The definitive diagnosis was then confirmed by in vitro reconstruction of the events: the suspected ET tube was placed in a transparent plastic tube of a diameter comparable to the trachea after being warmed up to mimic the body's temperature (Hollis et al., 1996). The cuff was then inflated with air and it spontaneously herniated (Fig.3) as soon that a slight traction was exerted on the ET tube. The herniation was reproducible each time we inflated the cuff of this specific ET tube, while it was not possible with others.

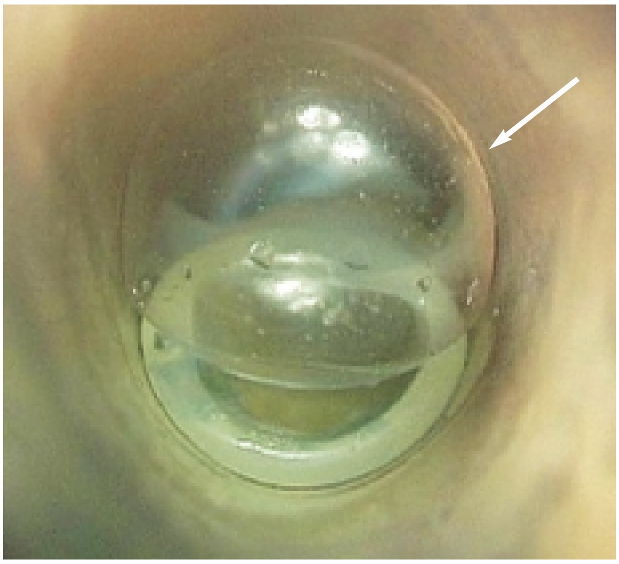

Figure 3: Herniation (arrow) of the endotracheal tube cuff, sagittal view.

Discussion

In both cases described in the present report the sudden occurrence of the clinical signs and changes in the monitored parameters suggested an acute airway obstruction. In the differential diagnoses acute bronchoconstriction should be considered (Bar-Lavie et al., 1995) but auscultation of both lungs of the patient should reveal stridor or wheezing and cuff deflation wouldn't result in an improvement. Intraluminal obstruction of the ET tube by secretions, blood, or foreign body was ruled out because it wouldn't resolve simply by cuff deflation. Also kinking of the tube was not likely as the tube was visually inspected and dogs head, neck and thorax were on a straight line (Harrington, 1984). Mechanical airway obstruction caused by herniation of the cuff has to be taken into account especially when all the symptoms resolve simply with partial cuff deflation. An excessive pressure and/or volume in the cuff can lead to different morphological patterns: 1) cuff herniation with protrusion and occlusion of the distal opening of the tube, 2) localised collapse of the tube with reduction/occlusion of the internal lumen or 3) intraluminal cuff hernia if the inflation tube is herniating in the ET tube lumen (Jost and Heimbach, 1982; Dorsch and Dorsch; 1998, Gantke, 1999) (Fig. 4).
Dilation of the ET tube cuff may occur because of primary accidental over-inflation or be secondary to diffusion of N_2O in the cuff (Davidson and Zimmer, 1989; Bar-Lavie et al., 1995; Hollis et al., 1996). Ideal cuff inflation is the volume or pressure that prevents air leakage around the tube. The pressure should be slightly lower than the capillary perfusion pressure (ca. 30 mmHg) to ensure an optimal perfusion of tracheal mucosa (Bernhard et al., 1985). In every day practice cuffs are often unintentionally over inflated and cuff pressures are greatly over 60 mmHg (Walker 2001, personal communication), especially in the high pressure-low volume types.

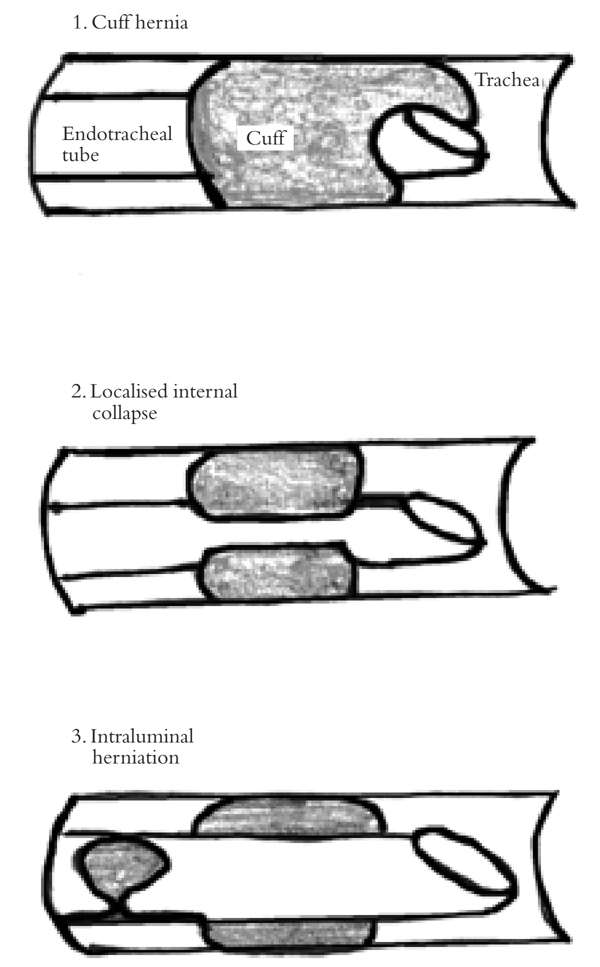

Figure 4: Cuff hernia types.

Nitrous oxide diffusibility is 34 times higher than nitrogen (N_2): for each N_2 molecule leaving, 34 molecules of N_2O can enter in an air filled pocket. This leads to a volume augmentation of any air filled pocket in the body i.e. the air inflated cuff of the ET tube when N_2O is used as a driver gas during anaesthesia. The cuff's increase in volume is proportional to concentration and duration of exposure to N_2O (Lanz and Zimmerschitt, 1976; Viallard et al., 1990). In case 1 the high fraction of N_2O ($F_{I N_2O}$ = 0.6) possibly contributed the early herniation of the cuff.
When N_2O is used, it's advisable to measure the pressure every 30 min or just deflate/reinflate the cuff during anaesthesia or to use "high volume-low pressure" cuffs that should be less prone to shape changing.

Other less practical options would be to fill the cuff with a N_2O/O_2 mixture (Viallard et al., 1990) or to use self releasing pilot balloons.

The diameter of the ET tube versus trachea, the material and the cuff type (high pressure-low volume vs. low pressure-high volume), local environment and the multiple use of single-use tubes with consequent material wear-out (Gantke, 1999) can be important contributing factors in determining whenever cuff herniation takes place. An unintentional traction over the ET tube associated to an over inflated cuff can lead to herniation as for case 2. After controlling all the 14 ID tubes in our clinic and considering the very short time interval between the 2 cases it is likely that the same ET tube was used. Finally the "murphy's eye" was ineffective in maintaining airway patency in both cases. The in vitro reconstruction showed that the herniation squeezes the ET tube and its murphy's eye against the tracheal wall. A part of the cuff can herniate through the murphy's eye in the lumen of the tube (Fig. 5).

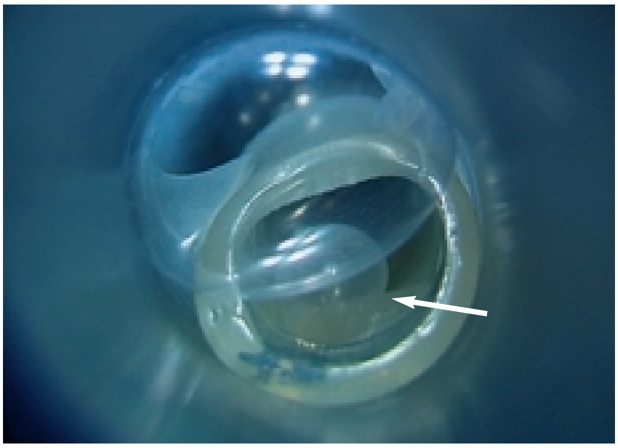

Figure 5: Double hernia through the Murphy's eye (arrow).

The cuff hernia behaves as a one way valve (Bar-Lavie et al., 1995) and gases remain entrapped in the lungs building a positive pressure with each inspiration, the lungs being mechanically ventilated. The lungs distend to their full capacity reducing the thorax excursions. If the problem is not recognized and resolved a tension pneumothorax can occur. The increase in intrathoracic pressure and decrease in thoracic compliance causes ventilatory impairment with hypercarbia, hypoxemia, and decreased venous return. Clinical signs are few, unspecific and can easily be missed, i.e. reduced thoracic excursions when the patient is covered by surgical draping. The feeling of increased resistance to manual ventilation and absence of gas flow through the tube should prompt to consider airway obstruction. To replace the ET tube is a security measure.

In the cases reported here the availability of extensive monitoring was extremely useful for an early recognition of the complication. The capnogram was initially normal with a typical sharp steep rise in expiratory CO_2 and an horizontal alveolar plateau, the dog being mechanically ventilated. The abnormal pathologic capnogram showed a slope in the expiratory phase without alveolar plateau (Fig. 1). This strongly suggests a severe degree of expiratory flow obstruction of mechanical or pathological (allergic bronchoconstriction, i.e.) nature (Smalhout and Kalenda, 1981). The morphologic change of the capnogram was the first sign of ventilation impairment and preceded changes in haemoglobin saturation and heart rate; a reduced and finally absent $ETCO_2$ was consistent with the progressive decrease in TV. A sudden reduction in cardiac output as a cause of decreased $ETCO_2$ could be ruled out because heart rate, arterial blood pressure, capillary refill time and mucous membrane colour remained in a physiologic range. The measured expiratory TV became zero indicating a total flow obstruction. Normalisation occurred following cuff deflation and a few breaths permitted entrapped air to be exhaled.

The anaesthesia monitor used provides continuous display of two spirometric loops: airways pressure versus inspired volume (P/V loop, Fig. 2) and flow versus inspired volume (Flow/Volume loop). Estimate of compliance and resistance in the respiratory system may be obtained by analysis of these loops on a breath to breath basis (Dorsch and Dorsch, 1998). If a constant TV is being used to ventilate a patient, the thoracic compliance visualized with the P/V loops will be inversely related to the inspiratory pressure. In this case the flattened slope of the P/V loops helped in quickly identifying the decreased compliance, but not the causative event; in first instance this was thought being consequent to positioning for surgery. To counteract for the decreased compliance the ventilation mode was changed from "volume" to "pressure controlled" which allows better ventilation of stiff lungs because of the different inspiratory flow pattern.

The dogs became hypoxemic – defined as $SpO_2 < 90\%$ – more than 6 min after cuff herniation as they were breathing a gas mixture with a high F_IO_2. Pulse oximetry was not a sensitive parameter to detect respiratory problems in both cases. Its accuracy can be reduced if the probe, placed over the tongue, is unintentionally moved while searching for the cause of the obstruction, pulse oximeters readings being very sensitive to movement artefacts. The anaesthetist must be aware of cuff herniation as a possible cause of acute airway obstruction. Monitoring is a valuable diagnostic aid, especially capnography. Intraoperative identification can be made by deflation of the cuff. Cuff pressures should be carefully managed and ideally measured with a manometer to keep pressure lower than 30 mmHg.

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