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RESEARCH PAPER

The effect of the inspired oxygen fraction on arterial blood oxygenation in spontaneously breathing, isoflurane anaesthetized horses: a retrospective study

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Abstract

Objectives To investigate the influence of two inspired oxygen fractions ($F_I'O_2$) on the arterial oxygenation in horses anaesthetized with isoflurane.

Study Design Retrospective, case-control clinical study.

Animals Two hundred equine patients undergoing non-abdominal surgery (ASA class 1–2), using a standardized anaesthetic protocol and selected from anaesthetic records of a period of three years, based on pre-defined inclusion criteria.

Methods In group O (n = 100), medical oxygen acted as carrier gas, while in group M (n = 100), a medical mixture of oxygen and air ($F_I'O_2$ 0.60) was used. Demographic data, $F_I'O_2$, arterial oxygen tension (PaO_2) and routinely monitored physiologic data were recorded. The alveolar-arterial oxygen tension difference [$P(A\text{-}a)O_2$] and $PaO_2/F_I'O_2$ ratio were calculated. The area under the curve, standardized to the anaesthetic duration, was calculated and statistically compared between groups using t-tests or Mann–Whitney tests as appropriate. Categorical data were compared using Chi-square tests.

Results No significant differences in age, body weight, sex, breed, surgical procedure, position, anaesthetic duration or arterial carbon dioxide tension were found. Mean $F_I'O_2$ was 0.78 in group O and 0.60 in group M. Compared to group O, significantly lower values for PaO_2 and for $P(A\text{-}a)O_2$ were found in group M. In contrast, the $PaO_2/F_I'O_2$ ratio and the percentage of horses with a PaO_2 <100 mmHg (13.33 kPa) were comparable in both groups.

Conclusions Although a reduction of the inspired oxygen fraction resulted in a lower PaO_2, the $P(A\text{-}a)O_2$ was also lower and the number of horses with PaO_2 values <100 mmHg was comparable.

Clinical relevance In healthy isoflurane anaesthetized horses, the use of a mixture of oxygen and air as carrier gas seems acceptable, but further, prospective studies are needed to confirm whether it results in a lower degree of ventilation/perfusion mismatching.

Keywords arterial oxygen tension, horse, inspired oxygen fraction.

Introduction

In anaesthetized horses, hypoxaemia is observed commonly due to ventilation-perfusion inequality

and right-to-left shunting of pulmonary blood, in turn caused by early atelectasis formation in dependent lung regions (Nyman et al. 1990). For this reason, 100% medical oxygen traditionally has been used as carrier gas during equine anaesthesia, with the aim to optimize oxygen uptake in ventilated lung regions as a compensation for atelectatic areas (Kerr & McDonell 2009). Nevertheless, the arterial oxygen tension (PaO_2) often remains low because the arterial oxygen content depends on the binding of oxygen to haemoglobin. In well-ventilated areas, the saturation of haemoglobin with oxygen is usually 100%, even when breathing room air. When using a higher inspired oxygen fraction, very little additional oxygen can be dissolved in plasma compared to the amount that is bound to haemoglobin. Consequently, increasing the inspired fraction of oxygen ($F_I'O_2$) results only in a very limited increase in arterial oxygen content in well-ventilated areas of the lung, which cannot (or only minimally) compensate for atelectatic areas when a significant degree of pulmonary shunt is present. This has been clearly illustrated in man in the so called 'isoshunt diagrams' (Benatar et al. 1973; Kerr & McDonell 2009).

It has been shown repeatedly, however, that an $F_I'O_2$ of 1.0 in the peri-operative period can result in more severe pulmonary atelectasis, so its routine use has been questioned. Atelectasis develops regularly during general anaesthesia in humans, with a reported prevalence of up to 75–90% in healthy patients during spontaneous or artificial ventilation. Collapsed lung fields may comprise 10–50% of the total lung tissue and this condition may persist for up to two days post-operatively (Hedenstierna & Rothen 2000; Magnusson & Spahn 2003; Duggan & Kavanagh 2005; Lumb 2010a; Edmark et al. 2011). Several mechanisms have been proposed to cause or contribute to the development of atelectasis, including lung compression, gas absorption, and surfactant impairment (Magnusson & Spahn 2003). The pressure exerted by abdominal organs in anaesthetized recumbent patients not only tends to compress the lungs ('compression atelectasis'), but at the same time, the functional residual capacity often drops below the closing volume of the lung, resulting in closure of small airways. Resorption of gases from alveoli distal to these collapsed airways then causes the so-called 'resorption' atelectasis (Lumb 2010a). During anaesthesia, the elevated $F_I'O_2$ increases the rate of gas absorption from occluded alveoli considerably. Furthermore, such increased gas absorption also may occur in lung fields that are not occluded but which have a low ventilation/perfusion ratio, and as a result the lung unit becomes progressively smaller. With both mechanisms, lung unit collapse will probably occur and atelectasis will develop (Magnusson & Spahn 2003; Duggan & Kavanagh 2005). The administration of an $F_I'O_2$ of 0.30–0.40 is currently suggested in human anaesthetic practice, unless the arterial blood oxygenation is compromised (Hedenstierna & Rothen 2000; Lumb 2010a).

In mechanically ventilated dogs, lung aeration and gas exchange were reported to be significantly better with an $F_I'O_2$ of 0.40 compared to an $F_I'O_2$ of 1.0 (Staffieri et al. 2007). Increased atelectasis development has also been reported when using 100% oxygen in anaesthetized animals, including cats (Staffieri et al. 2010a), sheep (Staffieri et al. 2010b) and horses. In halothane anaesthetized horses, an $F_I'O_2$ >0.85 was associated with an increased alveolar/arterial oxygen tension difference, although the PaO_2 remained constant (Cuvelliez et al. 1990). During tiletamine-zolazepam anaesthesia (spontaneous breathing, left lateral recumbency), arterial blood oxygenation was higher when horses inhaled >95% oxygen, than when they inhaled air. Interestingly however, breathing air decreased intrapulmonary shunt and reduced hypoventilation (Marntell et al. 2005). In mechanically ventilated, laterally recumbent horses, the inhalation of a gas mixture with a high helium-oxygen ratio was reported better to preserve lung function than the administration of high concentrations of oxygen during isoflurane anaesthesia. Moreover, a step-wise increase of the $F_I'O_2$ causes less impairment of pulmonary gas exchange than administration of a high $F_I'O_2$ immediately after induction of anaesthesia (Staffieri et al. 2009).

The ideal $F_I'O_2$ that optimizes arterial oxygenation and minimizes formation of resorption atelectasis has not been determined in horses. Some authors reported that the use of 30% (Levionnois & Kuich 2008) or 50% (Hubbell et al. 2011) oxygen did not improve arterial oxygenation or gas exchange compared to the use of >90% oxygen as carrier gas. In 2005, following the emerging evidence from medical and veterinary literature, our large animal clinic adopted a practice of reduced $F_I'O_2$ (60% oxygen) in all clinical cases of equine surgery (both elective and emergency operations). With the present retrospective study, the effect of this transition from 100% oxygen as the carrier gas (resulting most usually in

