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Efeito do aumento do diâmetro da sonda endotraqueal na mecânica pulmonar e na hemogasometria arterial de gatos anestesiados sob ventilação controlada por volume ou ventilação controlada por pressão

Tese apresentada à Faculdade de Medicina, Universidade Estadual Paulista "Júlio de Mesquita Filho", Câmpus de Botucatu, para obtenção do título de Doutor em Anestesiologia.

Orientador: Prof. Dr. Francisco José Teixeira Neto

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1. Gatos. 2. Respiração artificial. 3. Ventilação Pulmonar.

Palavras-chave: Gatos domésticos; Pressão de pico; Pressão de platô; Resistência das vias aéreas.

Dedicatória

"Aos meus pais e à minha irmã, por sempre acreditarem em mim. À minha avó e à minha tia, que já partiram, e de quem não pude me despedir adequadamente. As verei em um lugar melhor."

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À Coordenação de Aperfeiçoamento Pessoal de Nível Superior (CAPES) pela bolsa de estudos fornecida

Epígrafe

"If you're going to try, go all the way; otherwise, don't even start"

Charles Bukowsi

Capitulo 1

RESUMO

OSPINA, DA. **Efeito de um aumento de 50% no diâmetro interno da sonda endotraqueal na mecânica pulmonar em gatos anestesiados sob ventilação controlada por volume com uma pausa inspiratória prolongada.** Botucatu, 2024. 19p. Tese (Doutorado) – Faculdade de Medicina de Botucatu, Universidade Estadual Paulista, Botucatu.

Objetivo– Avaliar o efeito do aumento do diâmetro interno da sonda endotraqueal de 3,0 mm ($SE_{(3,0)}$) para 4,5 mm ($SE_{(4,5)}$) no gradiente entre a pressão de pico (P_{pico}) e a pressão de platô (P_{plat}) registrada durante a ventilação controlada por volume (VCV) com uma pausa inspiratória prolongada em gatos.
Delineamento experimental– Estudo experimental prospectivo.
Animais– Dez gatos hígidos (peso ideal: 4,22 ± 0,39 kg).
Material e Método– Após a administração de propofol, uma sonda endotraqueal ($SE_{(3,0)}$) foi inserida para a manutenção da anestesia com isoflurano (fração inspirada de oxigênio: 0,4). O gradiente $P_{pico} - P_{plat}$ registrado durante a VCV (volume corrente: 12 ml/kg) com uma pausa inspiratória > 0,5 seg foi usado como um índice estimativo da resistência das vias aéreas (R_{aw}). A P_{pico}, P_{plat}, gradiente $P_{pico} - P_{plat}$, complacência quase-estática (C_{qstat}) e a hemogasometria arterial foram mensurados após 10–15 minutos de estabilidade da profundidade anestésica/ausência de assincronia paciente-ventilador com a $SE_{(3,0)}$. Os animais foram reintubados com uma $SE_{(4,5)}$ e repetiu-se o mesmo protocolo. Empregou-se o teste t pareado ou o teste de Wilcoxon para comparação das variáveis obtidas com diferentes sondas endotraqueais ($p < 0,05$ considerado significativo).
Resultados– À medida que o diâmetro interno da sonda endotraqueal foi aumentado de 3,0 para 4,5 mm, a P_{pico} [mediana (valor mínimo e máximo)] diminuiu de 8 (6–10) cmH_2O para 7 (6–8) cmH_2O ($p < 0,0039$); enquanto a P_{plat} não apresentou alterações [6 (5–7) e 6 (5–7)] ($p > 0,99$). O aumento no diâmetro interno da sonda reduziu o gradiente $P_{pico} - P_{plat}$ de 2–3 mmHg para 1 mmHg em todos os gatos ($p = 0,0039$). A C_{qstat} e a hemogasometria arterial não foram alterados pela mudança no diâmetro interno da sonda endotraqueal.
Conclusões e relevância clínica– O gradiente $P_{pico} - P_{plat}$ é útil para detectar aumentos na R_{aw} causados por uma sonda endotraqueal estreita durante a VCV com uma pausa inspiratória > 0,5 seg. Em gatos com peso ideal próximo a 4 kg, o emprego de uma sonda com 4.5 mm pode ser preferível a uma sonda de 3.0 mm porque reduz a sonda de maior diâmetro reduz a P_{pico} durante a VCV.

Palavras-chave Gatos domésticos, pressão de pico, pressão de platô, resistência das vias aéreas

ABSTRACT

OSPINA, DA. **Effects of a 50% increase in endotracheal tube internal diameter on pulmonary mechanics recorded during volume-controlled ventilation with a prolonged inspiratory pause in cats.** Botucatu, 2023. 19p.Thesis (PhD) – São Paulo State University, School of Medicine, Botucatu.

Objective To evaluate the effects of increase in endotracheal tube internal diameter $ET_{tube(ID)}$ rom 3.0 mm ($ET_{tube(3.0)}$) to 4.5 mm ($ET_{tube(4.5)}$) on the gradient between peak inspiratory pressure (P_{peak}) and plateau pressure (P_{plat}) recorded during volume-controlled ventilation (VCV) with a prolonged inspiratory pause in cats.
Study design Prospective, experimental study.
Animal population Ten healthy cats [ideal body weight (IBW): 4.22 ± 0.39 kg].
Methods After propofol administration, an $ET_{tube(3.0)}$ was placed for maintenance of anesthesia with isoflurane (inspired oxygen fraction: 0.4). The $P_{peak} - P_{plat}$ gradient recorded during VCV (tidal volume: 12 mL kg^{-1}) with an inspiratory pause > 0.5 sec was used as a surrogate index of airway resistance (R_{aw}). P_{peak}, P_{plat}, $P_{peak} - P_{plat}$ gradient, quasistatic compliance (C_{qstat}), and arterial blood gases were measured after 10–15 min of stable depth of anesthesia/absence of patient-ventilator asynchrony with the $ET_{tube(3.0)}$. Animals were reintubated with an $ET_{tube(4.5)}$ and the same protocol was repeated. A paired t test or a Wilcoxon test compared data with different $ET_{tube(ID)}$ (p <0.05 considered significant).
Results As the $ET_{tube(ID)}$ was increased from 3.0 to 4.5 mm, P_{peak} [median (range)] decreased from 8 (6–10) cmH_2O to 7 (6–8) cmH_2O (p <0.0039); while P_{plat} did not change [6 (5–7) and 6 (5–7)] (p > 0.99). The increase in $ET_{tube(ID)}$ reduced the $P_{peak} - P_{plat}$ gradient from 2–3 cmH_2O to 1 cmH_2O in all cats (p = 0.0039). C_{qstat}, and arterial blood gases were unaltered by the change in $ET_{tube(ID)}$.
Conclusions and clinical relevance The $P_{peak} - P_{plat}$ gradient is useful to detect increases in R_{aw} caused by a narrow endotracheal tube during VCV with an inspiratory pause > 0.5 sec. In cats with an IBW close to 4 kg, an $ET_{tube(4.5)}$ can be favored in relation to an $ET_{tube(3.0)}$ because it lowers P_{peak}.

Keywords Airway resistance, domestic cats, peak airway pressure, plateau pressure

Introduction

The internal diameter of the endotracheal tube significantly contributes to total airway resistance (R_{aw}) in neonatal/pediatric human patients (Jarreau et al. 1999; Oca et al. 2002). According to the Ohm´s law, resistance to gas flow through an endotracheal tube result in a pressure drop (ΔP) from one end to another end of the tube at a given flow rate (Mitchell & Jones 2005; Lumb &Thomas 2021):

$$\text{Resistance to gas flow} = \frac{\Delta P}{\text{Flow rate}}$$

If the gas flow follows a laminar pattern, resistance can be calculated by combining the Ohm´s law with the Hagen-Poiseuille equation (Mitchell & Jones 2005; Lumb & Thomas 2021):

$$\text{Resistance to gas flow} = \frac{8 \times \text{gas viscosity} \times \text{length of tube}}{\pi \times (\text{radius of the tube})^4}$$

From the equation above, besides gas viscosity, an increase in the length of the tube and a reduction in its ID/radius will increase resistance to gas flow (Mitchell & Jones 2005; Lumb & Thomas 2021). The endotracheal tube internal diameter ($ET_{tube(ID)}$) is of critical importance in neonatal/pediatric human patients, where seemingly small reductions in endotracheal tube size may cause a major impact on R_{aw} (Oca et al. 2002). By applying the equation above, if an adult cat is intubated with a 3.0 mm internal diameter endotracheal tube ($ET_{tube(3.0)}$) instead of a 4.5 mm internal diameter endotracheal tube ($ET_{tube(4.5)}$) of the same length, resistance to gas flow will increase by approximately 5 times with the narrower endotracheal tube.

In patients who are breathing spontaneously an increase in total R_{aw} caused by a narrow endotracheal tube negatively impacts respiratory function by increasing the work of breathing (Lumb & Tomas 2021). In animals receiving volume-controlled ventilation (VCV) with a constant inspiratory flow an increase in R_{aw} is expected to increase peak airway pressure (P_{peak}) (Kaczka et al. 2019). However, an increase P_{peak} measured at the end of a constant inspiratory flow during VCV reflects not only the energy spent to overcome the frictional resistance imposed by the airways (R_{aw}), but also the viscoelastic properties of the respiratory

system (Barberis et al. 2003; Henderson & Sheel 2012). If a pause in inspiratory flow of at least 0.5 seconds is added after the target tidal volume (V_T) is achieved during VCV, the plateau pressure (P_{plat}) measured at the end of the zero flow period may reflect only the energy spent to overcome the viscoelastic properties of the respiratory system (Barberis et al. 2003; Henderson & Sheel 2012). Therefore, an increase in gradient between P_{peak} and P_{plat} in VCV mode with a prolonged inspiratory pause will be the result of an increase in total R_{aw} (Barberis et al. 2003; Henderson & Sheel 2012; Kaczka et al. 2019).

Because cats are prone to laryngospasm upon induction of anesthesia, some clinicians may favor the use of narrower endotracheal tubes to facilitate intubation, especially if the arytenoids are not fully relaxed/abducted. The hypothesis of the present study was that the gradient between P_{peak} and P_{plat} recorded during VCV with a relatively long inspiratory pause (> 0.5 seconds) would allow to detect a decrease in R_{aw} caused by a 50% increase in $ET_{tube(ID)}$ (from 3.0 mm to 4.5 mm), and the use of a larger endotracheal tube size would be beneficial because it would reduce P_{peak} in anesthetized cats receiving VCV.

Barberis L, Manno E, Guérin C (2003) Effect of end-inspiratory pause duration on plateau pressure in mechanically ventilated patients. Intensive Care Med 29, 130-134.

Becvarova I (2011) Canine and feline obesity: frequently asked questions and their answers. Compend Contin Educ Vet 33, E2.

Carrié S, Anderson TA (2015) Volatile anesthetics for status asthmaticus in pediatric patients: a comprehensive review and case series. Paediatr Anaesth 25, 460-407.

Conti G, De Blasi RA, Lappa A et al. (1994). Evaluation of respiratory system resistance in mechanically ventilated patients: the role of the endotracheal tube. Intensive Care Med 20, 421-424.

Dale WA, Rahn H (1952) Rate of gas absorption during atelectasis. Am J Physiol 170, 606-615

Dantzker DR, Wagner PD, West JB (1974) Proceedings: instability of poorly ventilated lung units during oxygen breathing. J Physiol, 242: 72.

Dye JA, McKiernan BC, Rozanski EA et al. (1996) Bronchopulmonary disease in the cat: historical, physical, radiographic, clinicopathologic, and pulmonary functional evaluation of 24 affected and 15 healthy cats. J Vet Intern Med 10, 385-400.

Ewart SL (2020) Overview of Respiratory Function: Ventilation of the Lungs. In: Cunningham's Textbook of Veterinary Physiology (6th ed). Klein BG (ed) Elsevier, NL. pp. 518-531.

Farstad T, Bratlid D (1991) Effects of endotracheal tube size and ventilator settings on the mechanics of a test system during intermittent flow ventilation. Pediatr Pulmonol 11, 15-21.

German AJ, Holden SL, Moxham GL et al. (2006) A simple, reliable tool for owners to assess the body condition of their dog or cat. J Nutr 136, 2031S-2033S.

Habre W, Asztalos T, Sly PD et al. (2001). Viscosity and density of common anaesthetic gases: implications for flow measurements. Br J Anaesth 87, 602-607.

Henderson WR, Sheel AW (2012) Pulmonary mechanics during mechanical ventilation. Respir Physiol Neurobiol 180, 162-172.

Hess DR (2014) Respiratory mechanics in mechanically ventilated patients. Respir Care 59, 1773-1794.

Jarreau PH, Louis B, Dassieu G et al. (1999) Estimation of inspiratory pressure drop in neonatal and pediatric endotracheal tubes. J Appl Physiol 87, 36-46.

Kaczka DW, Chiitilian HV, Melo MFV (2019) Respiratory monitoring. In: Miller's Anesthesia, (9th edn). Gropper M, Eriksson L, Fleisher L, et al. (eds). Elsevier, NL. pp. 1298-1339.

Li Y, Lu Y, Tan X et al. (2022) Effect of endotracheal tube size on airway resistance and dynamic lung compliance. Medicine (Baltimore) 101, e31410.

Lumb AB, Thomas C (2021) Respiratory system resistance. In: Nunn and Lumb's Applied Respiratory Physiology (9th edn). Lumb AB, Thomas C (eds). Elsevier, NL. pp. 27-41.

Mitchell V, Jones H (2005) Gas, tubes and flow. Anaesth & Intensive Care Med 6, 240-242.

Miyake F, Suga R, Takahiro A et al. (2018) An in vitro evaluation of the influence of neonatal endotracheal tube diameter and length on the work of breathing. Paediatr Anaesth 28, 458-462.

Mondoñedo JR, Herrmann J, McNeil JS et al. (2017). Comparison of pneumotachography and anemometery for flow measurement during mechanical ventilation with volatile anesthetics. J Clin Monit Comput 31, 1263-1271.

Nyktari VG, Papaioannou AA, Prinianakis G et al. (2006) Effect of the physical properties of isoflurane, sevoflurane, and desflurane on pulmonary resistance in a laboratory lung model. Anesthesiology 104, 1202-1207.

Nyktari V, Papaioannou A, Volakakis N et al. (2011) Respiratory resistance during anaesthesia with isoflurane, sevoflurane, and desflurane: a randomized clinical trial. Br J Anaesth 107, 454-472.

Oca MJ, Becker MA, Dechert RE et al. (2002) Relationship of neonatal endotracheal tube size and airway resistance. Respir Care 7, 994-997.

Spaeth J, Steinmann D, Kaltofen H et al. (2014) The pressure drop across the endotracheal tube in mechanically ventilated pediatric patients. Paediatr Anaesth 25, 413-420.

Staffieri F, De Monte V, De Marzo C, et al. (2010) Effects of two fractions of inspired oxygen on lung aeration and gas exchange in cats under inhalant anaesthesia. Vet Anaesth Analg 37, 483-482.

Takahashi K, Toyama H, Kubo R et al. (2023) Effectiveness of substantial shortening of the endotracheal tube for decreasing airway resistance and increasing tidal volume during pressure-controlled ventilation in pediatric patients: a prospective observational study. J Clin Monit Comput 37, 1513-1519.

References:

Akça O (2007) Endotracheal tube cuff leak: can optimum management of cuff pressure prevent pneumonia? Crit Care Med 35, 1624-1626.

Al-Majed SI, Thompson JE, Watson KF et al. (2004) Effect of lung compliance and endotracheal tube leakage on measurement of tidal volume. Crit Care 8, R398-402.

Barberis L, Manno E, Guérin C (2003) Effect of end-inspiratory pause duration on plateau pressure in mechanically ventilated patients. Intensive Care Med 29, 130-134.

Becvarova I (2011) Canine and feline obesity: frequently asked questions and their answers. Compend Contin Educ Vet 33, E2.

Dhaliwal MS; Raghunathan V, Sharma, J et al. (2015) Ventilator graphics: a step wise approach & clinical application. J Pediatr Crit Care 2, 67-84.

Dye JA, McKiernan BC, Rozanski EA et al. (1996) Bronchopulmonary disease in the cat: historical, physical, radiographic, clinicopathologic, and pulmonary functional evaluation of 24 affected and 15 healthy cats. J Vet Intern Med 10, 385-400.

German AJ, Holden SL, Moxham GL et al. (2006) A simple, reliable tool for owners to assess the body condition of their dog or cat. J Nutr 136, 2031S-2033S.

Hamilton VA, Grap MJ (2012) The role of the endotracheal tube cuff in microaspiration. Heart Lung 41, 167-172.

Henderson WR, Sheel AW (2012) Pulmonary mechanics during mechanical ventilation. Respir Physiol Neurobiol 180, 162-172.

Hess D, Tabor T (1993) Comparison of six methods to calculate airway resistance during mechanical ventilation in adults. J Clin Monit 9, 275-282.

Hess DR (2014) Respiratory mechanics in mechanically ventilated patients. Respir Care 59, 1773–1794.

Hess DR, Kacmarek RM (2019) Essentials of Mechanical Ventilation (4th edn), McGraw Hill, New York, NYC.

Jonson B, Nordström L, Olsson SG et al. (1975) Monitoring of ventilation and lung mechanics during automatic ventilation. A new device. Bull Physiopathol Respir (Nancy) 11, 729-743.

Kaczka DW, Chiitilian HV, Melo MFV (2019) Respiratory monitoring. In: Miller's Anesthesia, (9th edn). Gropper M, Eriksson L, Fleisher L, et al. (eds). Elsevier, US. pp. 1298-1339.

Lucangelo U, Bernabé F, Blanch L (2005) Respiratory mechanics derived from signals in the Ventilator Circuit. Respir Care 50, 55-65.

Schick V, Dusse F, Eckardt R et al. (2021) Comparison of volume-guaranteed or -targeted, pressure-controlled ventilation with volume-controlled ventilation during elective surgery: a systematic review and meta-analysis. J Clin Med 10, 1276.

Silva PL, Rocco PRM (2018) The basics of respiratory mechanics: ventilator-derived parameters. Ann Transl Med 6, 376.

Takahashi K, Toyama H, Kubo R et al. (2023) Effectiveness of substantial shortening of the endotracheal tube for decreasing airway resistance and increasing tidal volume during pressure-controlled ventilation in pediatric patients: a prospective observational study. J Clin Monit Comput 37, 1513-1519.

Ward J, Noel C (2022) Basic modes of mechanical ventilation. Emerg Med Clin North Am 40, 473-488.