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CAPNOGRAPHY IN THE MONITORING AND MANAGEMENT OF CARDIOPULMONARY ARREST DURING GENERAL ANESTHESIA

A capnografia na monitorização e condução da parada cardiorrespiratória em anestesia geral

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Abstract

Veterinary anesthetic monitoring has increasingly incorporated continuous monitoring methods that enhance patient safety. In this context, capnography stands out by providing real-time information on ventilation, perfusion, and anesthetic circuit function through capnographic waveform analysis and the measurement of end-tidal carbon dioxide ($ETCO_2$). This article reviews the applications of capnography in anesthetic monitoring and in the management of cardiopulmonary arrest during general anesthesia, with particular emphasis on $ETCO_2$ as an indicator of cardiopulmonary resuscitation quality, perfusion generated by chest compressions, and the return of spontaneous circulation. An abrupt decrease in $ETCO_2$ may indicate hemodynamic collapse, whereas a sustained increase suggests improved perfusion and a possible return of spontaneous circulation. Therefore, continuous interpretation of $ETCO_2$ supports rapid clinical decision-making, standardizes resuscitation procedures, and enhances anesthetic safety in Veterinary Medicine.

Keywords: carbon dioxide; $ETCO_2$; alveolar ventilation; perfusion; return of spontaneous circulation.

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Resumo

A monitorização anestésica veterinária vem incorporando métodos contínuos capazes de ampliar a segurança do paciente. Nesse contexto, a capnografia destaca-se por fornecer, em tempo real, informações sobre ventilação, perfusão e funcionamento do circuito anestésico, por meio do traçado capnográfico e da mensuração do dióxido de carbono ao final da expiração ($ETCO_2$). Este artigo revisa as aplicações da capnografia na monitorização e na condução da parada cardiorrespiratória durante a anestesia geral, com ênfase no $ETCO_2$ como indicador da qualidade da reanimação cardiopulmonar, da perfusão gerada pelas compressões torácicas e do retorno da circulação espontânea. A queda abrupta do $ETCO_2$ pode sinalizar colapso hemodinâmico, enquanto sua elevação sustentada sugere melhora da perfusão e possível retorno da circulação espontânea. Dessa forma, a interpretação contínua do $ETCO_2$ contribui para a tomada de decisão rápida, a padronização das manobras de reanimação e o aumento da segurança anestésica em Medicina Veterinária.

Palavras-chave: dióxido de carbono; $ETCO_2$; ventilação alveolar; perfusão; retorno da circulação espontânea.

Introduction

Anesthetic monitoring in veterinary medicine has advanced significantly in recent decades, incorporating technologies that enhance patient safety and improve clinical outcomes. In this context, continuous monitoring methods, such as capnography and capnometry, enable the ongoing assessment of ventilation and perfusion throughout the anesthetic procedure. While capnography graphically records changes in exhaled carbon dioxide (CO_2) over the respiratory cycle, capnometry provides a numerical measurement, including the end-tidal carbon dioxide ($ETCO_2$) value (Griffiths; Murison, 2016).

During general anesthesia, these monitoring tools are essential for confirming correct endotracheal tube placement, assessing the effectiveness of ventilation, and enabling the early detection of respiratory or circulatory adverse events (Bailey *et al*., 2025; Grubb *et al*., 2020). Furthermore, during cardiopulmonary arrest, $ETCO_2$ measurement is recommended to assess the quality of chest compressions and assist in identifying the return of spontaneous circulation (ROSC), as $ETCO_2$ values correlate with the pulmonary blood flow generated by cardiopulmonary resuscitation (CPR) maneuvers (Brainard *et al*., 2024; Hogen; Cole; Drobatz, 2018).

Although clinical veterinary studies remain limited, recent guidelines recognize capnography as a valuable tool for identifying hemodynamic deterioration, assessing the quality of cardiopulmonary resuscitation (CPR), and detecting ROSC in dogs and cats. Its integration into anesthetic monitoring and resuscitation protocols supports earlier, more standardized clinical interventions (Bailey *et al*., 2025; Brainard *et al*., 2024; Grubb *et al*., 2020).

In light of these considerations, the present study aims to critically review the applications of capnography in monitoring and managing cardiopulmonary arrest during general anesthesia in Veterinary Medicine, with particular emphasis on the interpretation of $ETCO_2$ as an indicator of cardiopulmonary resuscitation quality, perfusion generated by chest compressions, and the return of spontaneous circulation. Additionally, the study discusses the limitations of capnography and its future prospects for clinical application.

Applications in general anesthesia

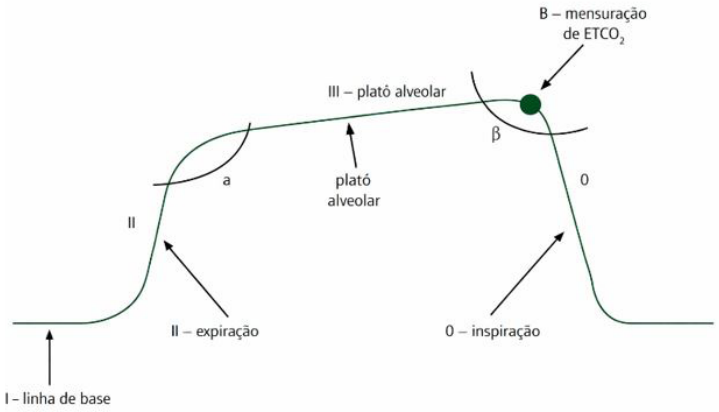
Capnography is an essential anesthetic monitoring tool for pulmonary assessment because it enables the continuous evaluation of ventilation and perfusion through the analysis of exhaled carbon dioxide (CO_2) and the measurement of end-tidal carbon dioxide ($ETCO_2$). CO_2 is produced through

aerobic metabolism in perfused tissues, diffuses from the cells into the bloodstream, and is transported to the lungs via the venous circulation, where it is eliminated through ventilation. Therefore, the primary determinants of $ETCO_2$ are CO_2 production, cardiac output, pulmonary perfusion, and alveolar ventilation (Sandroni; De Santis; D'Arrigo, 2018).

Under conditions of adequate ventilation and perfusion, normal $ETCO_2$ values range from 35 to 45 mmHg. These values correlate with the arterial partial pressure of carbon dioxide ($PaCO_2$), with $ETCO_2$ typically measuring approximately 5 mmHg lower than $PaCO_2$ in small animals. In large animals, this difference may range from 15 to 30 mmHg.

In addition to the numerical $ETCO_2$ value, the capnogram generated by the capnograph provides a graphical representation of CO_2 fluctuations throughout the respiratory cycle, allowing continuous assessment of the patient's gas exchange. This waveform follows the respiratory pattern and can be divided into distinct phases, as illustrated in Figure 1 (Deighton, 2018). Before the expiratory phase begins, the air within the airways contains negligible concentrations of CO_2, keeping the tracing close to the baseline. At the onset of expiration, the CO_2 concentration rises sharply as alveolar gas begins to be exhaled. This is followed by an expiratory plateau, with the highest point of the graph at the end of the plateau corresponding to the $ETCO_2$ value. Subsequently, with the onset of inspiration, the tracing rapidly returns to the baseline (Nunes, 2009).

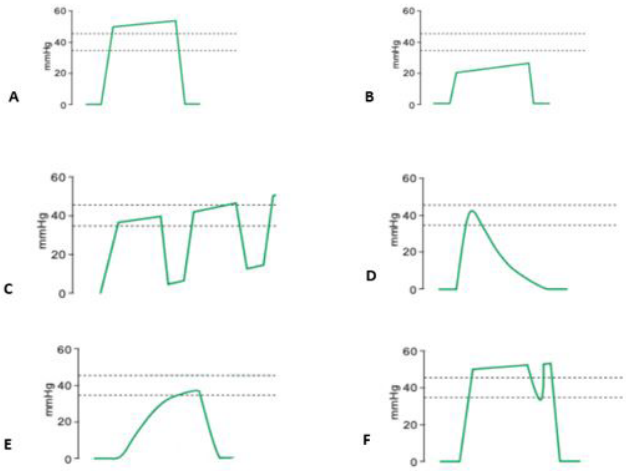
Figure 1 – Normal capnographic waveform illustrating the phases of the respiratory cycle: inspiratory baseline, expiratory upstroke, alveolar plateau, and end-expiratory point corresponding to the $ETCO_2$ value



Source: Deighton (2018, adapted).

During anesthesia, immediately after endotracheal intubation, capnography is considered the most reliable method for confirming correct tracheal tube placement, as the presence of a sustained CO_2 waveform during expiration confirms proper positioning. Furthermore, throughout the anesthetic procedure, capnographic monitoring enables the early detection of deviations from the normal waveform that indicate changes in respiratory dynamics, including hypercapnia, hypocapnia, CO_2 rebreathing, contamination of the gas sample with ambient air, bronchospasm, and active breathing against the ventilator, as illustrated in Figure 2.

Figure 2 – Capnographic waveform abnormalities observed during anesthetic monitoring: (A) hypercapnia; (B) hypocapnia; (C) CO_2 rebreathing; (D) contamination of the gas sample with ambient air; (E) bronchospasm; and (F) active breathing against the ventilator



Source: Luna and Carregaro (2019, adapted).

During intra-anesthetic monitoring, in cases of cardiopulmonary arrest under anesthesia, an abrupt decrease in $ETCO_2$ is one of the earliest indicators of hemodynamic collapse. Likewise, during the postoperative period, changes in $ETCO_2$ may provide an early indication of respiratory depression, preceding a decline in peripheral oxygen saturation (SpO_2) (Shippy, 2024). Thus, capnography serves not only as a method for monitoring ventilation but also as an important tool for patient safety, early diagnosis, and prognostic assessment.

Capnography and capnometry during cardiopulmonary arrest

Early diagnosis: A decrease in $ETCO_2$ as an Initial Indicator

An acute and sustained decrease in $ETCO_2$ values in dogs and cats, after excluding mechanical factors (such as circuit disconnection) and respiratory causes (such as iatrogenic hyperventilation), should be interpreted as an early marker of hemodynamic instability. In this context, because of the direct relationship between pulmonary blood flow and exhaled CO_2, $ETCO_2$ serves as a noninvasive indicator of cardiac output and has the ability to signal impending cardiovascular collapse even before changes in systemic arterial pressure become evident (Haskins, 2015; Nunes, 2009).

Accordingly, in situations involving a sudden reduction in cardiac output, such as cardiopulmonary arrest, $ETCO_2$ decreases markedly because reduced pulmonary perfusion limits the transport of CO_2 to the lungs for elimination during exhalation. Conversely, the return of spontaneous circulation (ROSC) results in a sudden increase in $ETCO_2$ concentration (Brainard *et al*., 2024; Grubb *et al*., 2020; Shippy, 2024).

Therefore, capnography and capnometry are valuable tools in emergency settings, as they assist the veterinary team in the early recognition of hemodynamic disturbances that require prompt identification and correction (Bailey *et al*., 2025).

CPR monitoring: The relationship between $ETCO_2$ and chest compression quality

During cardiopulmonary resuscitation (CPR), continuous $ETCO_2$ monitoring is recommended to assess the effectiveness of chest compressions and the blood flow they generate, since higher $ETCO_2$ values are associated with greater effective cardiac output produced during CPR (Brainard *et al*., 2024). Consistent with this, the most recent guidelines of the Reassessment Campaign on Veterinary Resuscitation (RECOVER) recognize capnography as a key tool during the intraoperative period for monitoring chest compression quality and detecting ROSC (Brainard *et al*., 2024). In the 2024 guideline update, the minimum $ETCO_2$ target during CPR was increased to 18 mmHg, with the aim of guiding the need for immediate adjustments to resuscitation technique, including compression depth, complete chest recoil, compression rate, hand positioning, and frequent rotation of the individual performing chest compressions (Burkitt-Creedon *et al*., 2024; Hopper *et al*., 2024).

Accordingly, for $ETCO_2$ to function effectively as a hemodynamic feedback parameter, ventilation must be standardized in accordance with current recommendations, which specify 10 breaths per minute with an inspiratory time of approximately 1 second. This approach minimizes the risk of hyperventilation and reduces interruptions in chest compressions (Hopper *et al*., 2024).

In this context, attention should be given to interference and artifacts produced by chest compressions that may impair the detection of ventilation. According to Sandroni, De Santis, and D'Arrigo (2018), the interpretation of $ETCO_2$ values should take into account factors that may affect the measurement independently of compression quality. Pre-arrest hypercapnia may lead to an overestimation of CPR effectiveness because elevated $ETCO_2$ values observed during the initial phase of resuscitation result from the rapid elimination of previously retained CO_2 rather than from the quality of chest compressions. Conversely, iatrogenic hyperventilation lowers $ETCO_2$ levels by increasing alveolar CO_2 elimination. Furthermore, the administration of epinephrine may cause a transient decrease in $ETCO_2$ due to pulmonary vasoconstriction, which should not be misinterpreted as evidence of ineffective resuscitation technique.

Prognostic value: $ETCO_2$ as a predictor of ROSC

In addition to guiding the quality of chest compressions, $ETCO_2$ monitoring during CPR also serves as a valuable prognostic tool. In dogs and cats, higher initial, mean, and peak $ETCO_2$ values are significantly associated with the occurrence of return of spontaneous circulation (ROSC) (Hogen; Cole; Drobatz, 2018). In human studies, persistently low $ETCO_2$ values (generally <10–15 mmHg) for more than 20 minutes of CPR have been associated with poor prognosis and unsuccessful cardiopulmonary resuscitation (Sandroni; De Santis; D'Arrigo, 2018).

From a clinical perspective, the earliest indicator of ROSC is a sudden and sustained increase in $ETCO_2$ values in the absence of changes in ventilation. This phenomenon reflects an abrupt improvement in venous return and tissue perfusion and should prompt the veterinary team to immediately assess the patient's pulse and cardiac rhythm (Sandroni; De Santis; D'Arrigo, 2018). Similarly, in anesthetized patients, a sudden decrease in $ETCO_2$ may indicate impending circulatory collapse or cardiopulmonary arrest (CPA), requiring immediate intervention (Brainard *et al*., 2024).

Human studies have shown that $ETCO_2$ values generally decline during CPR in patients who do not achieve successful resuscitation, whereas they tend to increase in those who attain ROSC, likely reflecting the progressive improvement in venous return and tissue perfusion. Consequently, $ETCO_2$ trends may help predict ROSC during CPR, although further evidence is needed to strengthen this association (Sandroni; De Santis; D'Arrigo, 2018).

Because direct measurement of organ blood flow during CPR is not clinically feasible, $ETCO_2$ has emerged as a valuable noninvasive indicator of both the effectiveness of resuscitation maneuvers and the likelihood of successful resuscitation, as it reflects the pulmonary blood flow generated by chest compressions. Therefore, capnography serves not only as a method of ventilatory monitoring but also as an important tool for patient safety, diagnosis, and prognostic assessment (Brainard *et al*., 2024; Hogen; Cole; Drobatz, 2018).

Final Considerations

Capnography should be regarded as a core component of anesthetic monitoring in Veterinary Medicine because it enables real-time assessment of ventilation, facilitates the detection of abnormalities in the anesthetic circuit, and allows the early identification of signs of cardiorespiratory instability. In cases of cardiopulmonary arrest, continuous $ETCO_2$ monitoring contributes to the assessment of chest compression effectiveness, guides adjustments during cardiopulmonary resuscitation, and assists in the identification of return of spontaneous circulation. Therefore, its routine use in dogs and cats promotes faster, more standardized, and safer clinical decision-making, thereby enhancing the quality of patient care in both anesthetic and emergency settings. &

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- **Author contributions:** ALENCAR, B. de: contributed to the study conception, literature search, drafting of the initial manuscript, and manuscript revision. PRATES, M. C. F.; DINIZ, E. D.; SANTOS, N. M. dos; and CORREIA, T. M. S. contributed to the literature search, literature analysis, and manuscript preparation. GUIMARÃES, P. C. and FERRUCCIO, C. A. contributed to the supervision of the study, critical revision of the manuscript, and approval of the final version. All authors read and approved the final version of the manuscript.

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