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Influence of Thoracic Conformation on Ventilatory and Haemodynamic Responses to Pneumoperitoneum in Dogs: A Spirometric Study

Liliana Filipa Pereira Gonçalves

Project – Final Dissertation

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RESUMO

O pneumoperitoneu é reconhecido por induzir alterações respiratórias e hemodinâmicas relevantes durante procedimentos laparoscópicos; contudo, a influência da conformação torácica na mecânica ventilatória e na eliminação do CO_2 em cães permanece incompletamente caracterizada. Este estudo experimental prospetivo avaliou os efeitos ventilatórios, gasométricos e hemodinâmicos do pneumoperitoneu em 64 cães ASA I, submetidos a procedimentos laparoscópicos, com particular enfoque no papel da conformação torácica, recorrendo à espirometria contínua e à análise de gasometria venosa. Os cães foram classificados como de tórax largo, intermédio ou profundo e anestesiados sob ventilação controlada por pressão. As variáveis ventilatórias, capnográficas e hemodinâmicas foram monitorizadas continuamente, sendo realizadas colheitas de sangue venoso em momentos pré-definidos para análise gasométrica. Os dados foram analisados através de comparações pareadas, análises de correlação e modelos lineares de efeitos mistos. O pneumoperitoneu induziu reduções significativas do volume tidal, da ventilação minuto e da complacência dinâmica, acompanhadas por aumento da resistência das vias aéreas e retenção de CO_2 (todos $p < 0,001$). A análise gasométrica venosa, utilizada como método de monitorização indireta das alterações ácido-base e da retenção de CO_2, revelou uma alteração compatível com uma perturbação ácido-base predominantemente respiratória, caracterizada por aumento da pCO_2 e diminuição do pH ($p < 0,001$). A conformação torácica influenciou significativamente a mecânica ventilatória basal. Além disso, modulou a magnitude e a evolução temporal das alterações da complacência dinâmica e do volume tidal, enquanto os efeitos gasométricos e hemodinâmicos cumulativos não diferiram significativamente entre grupos. Observou-se uma forte associação entre as alterações cumulativas da pCO_2 venosa e do $EtCO_2$ ($r = 0,69$; $p < 0,001$), suportando a utilidade clínica da capnografia como indicador indireto das alterações gasométricas. Observou-se ainda elevada variabilidade no tempo de normalização do $EtCO_2$ após a desinsuflação. Estes resultados demonstram que o pneumoperitoneu induz alterações significativas e persistentes da mecânica respiratória e da eliminação do CO_2 em cães anestesiados, sendo a conformação torácica um importante modulador das respostas ventilatórias. A monitorização espirométrica contínua revelou-se uma ferramenta sensível para caracterizar estas alterações, fornecendo informação complementar aos parâmetros anestésicos convencionais e apoiando estratégias ventilatórias mais individualizadas durante procedimentos laparoscópicos.

PALAVRAS-CHAVE: capnografia; cães; conformação torácica; espirometria; laparoscopia; pneumoperitoneu; ventilação mecânica.

ABSTRACT

Pneumoperitoneum is recognised to induce relevant respiratory and haemodynamic alterations during laparoscopic procedures; however, the influence of thoracic conformation on respiratory mechanics and CO_2 elimination in dogs remains incompletely characterised. This prospective experimental study evaluated the ventilatory, venous blood gas and haemodynamic effects of pneumoperitoneum in 64 ASA I dogs undergoing laparoscopic procedures, with particular emphasis on the role of thoracic conformation, using continuous spirometry and venous blood gas analysis. Dogs were classified as broad-, intermediate- or deep-chested and anaesthetised under pressure-controlled mechanical ventilation. Ventilatory, capnographic and haemodynamic variables were continuously monitored, and venous blood samples were collected at predefined time points for venous blood gas analysis. Data were analysed using paired comparisons, correlation analyses and linear mixed-effects models.

Pneumoperitoneum induced significant reductions in tidal volume, minute ventilation and dynamic compliance, accompanied by increased airway resistance and CO_2 retention (all $p < 0.001$). Venous blood gas analysis, used as an indirect method for monitoring acid–base alterations and CO_2 retention, revealed changes consistent with a predominantly respiratory acid–base disturbance, characterised by increased venous pCO_2 and decreased pH ($p < 0.001$). Thoracic conformation significantly influenced baseline respiratory mechanics. Furthermore, it modulated the magnitude and temporal evolution of changes in dynamic compliance and tidal volume, whereas cumulative venous blood gas and haemodynamic effects did not differ significantly between groups. A strong association was observed between cumulative changes in venous pCO_2 and end-tidal CO_2 ($EtCO_2$) ($r = 0.69$; $p < 0.001$), supporting the clinical utility of capnography as an indirect indicator of venous blood gas alterations. Considerable variability was also observed in the time required for $EtCO_2$ normalisation following desufflation.

These findings demonstrate that pneumoperitoneum induces significant and persistent alterations in respiratory mechanics and CO_2 elimination in anaesthetised dogs, with thoracic conformation representing an important modulator of ventilatory responses. Continuous spirometric monitoring proved to be a sensitive tool for characterising these alterations, providing complementary information to conventional anaesthetic

monitoring and supporting more individualised ventilatory strategies during laparoscopic procedures.

KEYWORDS: capnography; dogs; thoracic conformation; spirometry; laparoscopy; pneumoperitoneum; mechanical ventilation.

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ABBREVIATIONS AND ACRONYMS

A–a – Alveolar–arterial

ABG – Arterial blood gas

ACVS – American College of Veterinary Surgeons

Ar – Argon

ARM – Alveolar recruitment manoeuvre

ASA – American Society of Anesthesiologists

BE – Base excess

BSA – Body surface area

Cdyn – Dynamic compliance of the respiratory system

CL – Lung compliance

CO – Cardiac output

CI – Cardiac index

CO_2 – Carbon dioxide

Crs – Respiratory system compliance

Cstat – Static compliance

CT – Computed tomography

CW – Chest wall compliance

DV – Dorsoventral

DVT – Deep vein thrombosis

EAES – European Association for Endoscopic Surgery

ECG – Electrocardiography

ERV – Expiratory reserve volume

$EtCO_2$ – End-tidal carbon dioxide

ETT – Endotracheal tube

FiO_2 – Fraction of inspired oxygen

FRC – Functional residual capacity

FV – Flow–volume

GFR – Glomerular filtration rate

HCO_3^- – Bicarbonate

He – Helium

HR – Heart rate

HVLP – High-volume, low-pressure

IAP – Intra-abdominal pressure

IC – Inspiratory capacity

ICCs – Intraclass correlation coefficients

IPPV – Intermittent positive pressure ventilation

IQR – Interquartile range

IRV – Inspiratory reserve volume

IVC – Inferior vena cava

Lac – Lactate

LIP – Lower inflection point

LMA – Laryngeal mask airway

LMMs – Linear mixed-effects models

MAP – Mean arterial pressure

MIS – Minimally invasive surgery

MV – Mechanical ventilation

N_2 – Nitrogen

NIBP – Non-invasive blood pressure

N_2O – Nitrous oxide

NSAID – Non-steroidal anti-inflammatory drug

$PaCO_2$ – Arterial partial pressure of carbon dioxide

PAP – Pulmonary artery pressure

PaO_2 – Arterial partial pressure of oxygen

pCO_2 – Partial pressure of carbon dioxide

PCV – Pressure-controlled ventilation

PCWP – Pulmonary capillary wedge pressure

PEEP – Positive end-expiratory pressure

PEEPE – Extrinsic positive end-expiratory pressure

PEEPI – Intrinsic positive end-expiratory pressure

PiCCO – Pulse contour cardiac output

PIP – Peak inspiratory pressure

PL – Transpulmonary pressure

PNP – Pneumoperitoneum

POC – Point-of-care

PONV – Postoperative nausea and vomiting

PPlat – Plateau pressure

PV – Pressure–volume

PVC – Polyvinyl chloride

PVR – Pulmonary vascular resistance

RAAS – Renin–angiotensin–aldosterone system

RAP – Right atrial pressure

Raw – Airway resistance

REML – Restricted maximum likelihood

ROS – Reactive oxygen species

Rrs – Respiratory system resistance

Rtissue – Tissue resistance

RV – Residual volume

SD – Standard deviation

SpO_2 – Pulse oximetry–derived arterial oxygen saturation

SV – Stroke volume

SVR – Systemic vascular resistance

TAP – Transversus abdominis plane

TD – Thoracic depth

TD/TW – Depth-to-width ratio

TEE – Transesophageal echocardiography

TI – Thoracic index

TIVA – Total intravenous anaesthesia

TLC – Total lung capacity

TOF – Train-of-four

TW – Thoracic width

UIP – Upper inflection point

V/Q – Ventilation–perfusion

VBG – Peripheral venous blood gas

VC – Vital capacity

VCV – Volume-controlled ventilation

VD – Ventrodorsal

Vm – Minute ventilation

VT – Tidal volume

↑ – Increase

↓ – Decrease

↔ – Variable or unchanged response

% – Percentage

kg – Kilogram

min – Minute

mmHg – Millimetres of mercury

cm – Centimetres

cmH_2O – Centimetres of water

mL – Millilitres

L – Litre

≤ – Less than or equal to

≥ – Greater than or equal to

= – Equal to

< – Less than

°C – Degrees Celsius

1. INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

Minimally invasive surgery has become an integral part of small animal surgical practice due to its association with reduced surgical trauma, decreased postoperative pain, faster recovery, and improved cosmetic outcomes when compared with open procedures (Culp et al., 2009; Devitt et al., 2005; Milovancev & Townsend, 2015). Consequently, laparoscopic techniques are now routinely employed for diagnostic and therapeutic indications in dogs. However, laparoscopy should not be regarded as a routine or low-risk procedure, as pneumoperitoneum induces physiological disturbances that may be subtle, cumulative, and difficult to detect under general anaesthesia (Bleedorn et al., 2013; Hayden & Cowman, 2011).

The establishment of pneumoperitoneum through carbon dioxide insufflation increases intra-abdominal pressure and alters thoracoabdominal mechanics, leading to cranial displacement of the diaphragm, reduced lung volumes, changes in respiratory system compliance, and increased airway resistance, particularly in dorsal recumbency (Atkinson et al., 2017; Kaba & Joris, 2001; Koivusalo & Lindgren, 2000). In addition, systemic absorption of carbon dioxide may result in hypercapnia and respiratory acid–base disturbances, even in mechanically ventilated patients (Carraretto et al., 2005; Fantoni et al., 2016). The magnitude of these effects is influenced by intra-abdominal pressure, duration of insufflation, ventilatory strategy, and individual patient characteristics. Considerable interindividual variability has been reported in these physiological responses, suggesting that anatomical factors may contribute to differences in respiratory adaptation during pneumoperitoneum.

Among these factors, thoracic conformation is recognised as an important determinant of pulmonary function in dogs. Thoracic conformation has been associated with differences in lung capacity, chest wall compliance, diaphragmatic excursion, airway geometry and respiratory reserve, all of which may influence respiratory mechanics and ventilatory performance (Asorey et al., 2020; Corcoran, 1991; Fahy et al., 1995; Xu et al., 2025). Consequently, these anatomical differences may also influence the physiological response to pneumoperitoneum and mechanical ventilation. Dogs are commonly classified as broad-, intermediate-, or deep-chested based on thoracic depth-to-width ratios (Buchanan, 2000; Buchanan & Bücheler, 1995); however, unequal distribution of thoracic conformations across breeds may contribute to gaps in current knowledge (Castro et al., 2011; Soeratanapant et al., 2024).

Although the ventilatory and haemodynamic consequences of pneumoperitoneum have been widely investigated, much of the existing veterinary literature is based on highly controlled experimental models, often excluding small dogs and limiting population heterogeneity (Duke et al., 1996; Milovancev & Townsend, 2015; Vieira de Almeida & Marisa Ganem, 2004). This restricts the applicability of results to routine clinical practice and limits the understanding of factors that may explain interindividual variability in ventilatory responses.

Mechanical ventilation is a key component of anaesthetic management during laparoscopy, with pressure-controlled ventilation frequently selected to limit peak airway pressures while accommodating changes in respiratory system compliance (Vieira de Almeida et al., 2003). Nevertheless, conventional anaesthetic monitoring may not fully capture dynamic or cumulative alterations in ventilatory mechanics. Continuous spirometry provides real-time assessment of tidal volume, minute ventilation, dynamic compliance, airway resistance and ventilatory waveforms, allowing subtle changes in respiratory mechanics to be detected before conventional monitoring parameters become abnormal. Despite its potential clinical value, the application of continuous spirometry during veterinary laparoscopic procedures remains poorly described. Continuous spirometry therefore represents a valuable tool for supporting more precise and individualised ventilatory management during procedures that interfere with respiratory mechanics (Bradbrook et al., 2013; Calice & Moens, 2016; Raillard et al., 2022; Rozanski & Hoffman, 2004; Xu et al., 2025).

Assessment of gas exchange and acid–base balance further complements respiratory monitoring. While arterial blood gas analysis is considered the reference standard, peripheral venous blood gas analysis represents a less invasive and clinically feasible alternative in veterinary patients, particularly when combined with capnography (Hopper, 2015; Ilkiw et al., 1991). Portable point-of-care analysers facilitate real-time evaluation of cumulative metabolic and ventilatory effects during pneumoperitoneum (Bingham et al., 1999; Faria et al., 2024).

To the authors' knowledge, no prospective clinical study has simultaneously evaluated the influence of thoracic conformation on respiratory mechanics, carbon dioxide handling and perioperative gas exchange during pneumoperitoneum in a heterogeneous canine population using continuous intraoperative spirometry. The present study therefore aimed to evaluate the cumulative ventilatory, gasometric and haemodynamic effects of pneumoperitoneum in dogs with different thoracic conformations, integrating continuous spirometry with capnography, haemodynamic monitoring and venous blood gas analysis to support a more individualised and physiologically guided approach to ventilatory management during laparoscopic surgery in small animals.

1.2 OBJECTIVES

The primary aim of this study was to investigate the ventilatory, venous blood gas, and haemodynamic effects of pneumoperitoneum in dogs undergoing laparoscopic procedures under general anaesthesia, with particular emphasis on the influence of thoracic conformation.

Specifically, the study sought to:

Characterise pneumoperitoneum-induced alterations in respiratory mechanics using continuous spirometric monitoring;

Evaluate carbon dioxide handling and acid‑base status during insufflation and after desufflation;

Determine whether thoracic conformation influences baseline respiratory mechanics and modulates the magnitude and temporal evolution of ventilatory alterations induced by pneumoperitoneum;

Assess the relationship between capnographic, spirometric, and venous blood gas variables throughout the perioperative period.

A further objective was to evaluate post-desufflation recovery patterns and interindividual variability in physiological responses, with the aim of supporting more individualised and physiologically guided ventilatory management during laparoscopic surgery in small animals.

2. LITERATURE REVIEW

2.1 A BRIEF HISTORY OF LAPAROSCOPY AND PNEUMOPERITONEUM

The word *'laparoscopy'* is derived from the Greek '*laparo'*, meaning "flank", and '*scope'*, meaning "an instrument for observation". It is a term that is used to describe a procedure in which the peritoneal contents are examined using an endoscope (Spaner & Warnock, 1997).

The word '*pneumoperitoneum*' (PNP) has Greek origins. '*Pneumo*' means "air" or "gas", and '*peritoneum*' refers to the peritoneum, which is the membrane lining the abdominal cavity. Therefore, '*pneumoperitoneum*' means "presence of air or gas in the peritoneum" (Spaner & Warnock, 1997).

Minimally invasive surgery (MIS) in veterinary medicine has its roots in human surgical practices, with its adoption in veterinary clinical settings occurring approximately two decades later than in human medicine. This delay is attributed to the time required for technological advancements and the adaptation of techniques suitable for animal patients (Fransson & Mayhew, 2022).

The inception of endoscopic procedures dates back to 1806 when Philipp Bozzini attempted to visualize the urinary tract using a rudimentary device known as the "Lichtleiter" or "light conductor," considered a precursor to modern endoscopes (Engel, 2003; Fransson & Mayhew, 2022).

In 1901, Georg Kelling performed the first documented laparoscopy on a canine, utilizing filtered air to create a pneumoperitoneum. Subsequently, in 1924, carbon dioxide (CO_2) was introduced as the preferred insufflation gas due to its rapid absorption and reduced risk of gas embolism (Spaner & Warnock, 1997).

While early laparoscopic experiments in small animals were primarily conducted for human medical research, the 1970s marked the beginning of endoscopy's application in veterinary medicine, leading to a significant increase in its diagnostic and therapeutic use (Chamness, 2005; Culp et al., 2009; Petre et al., 2012; Srivastava & Niranjan, 2010).

A 2013 survey by Bleedorn et al. (2013) revealed that 86% of small animal diplomates of the American College of Veterinary Surgeons (ACVS) incorporated MIS into their practice, indicating a steady rise in its adoption over time (Figure 1) (Bleedorn et al., 2013).

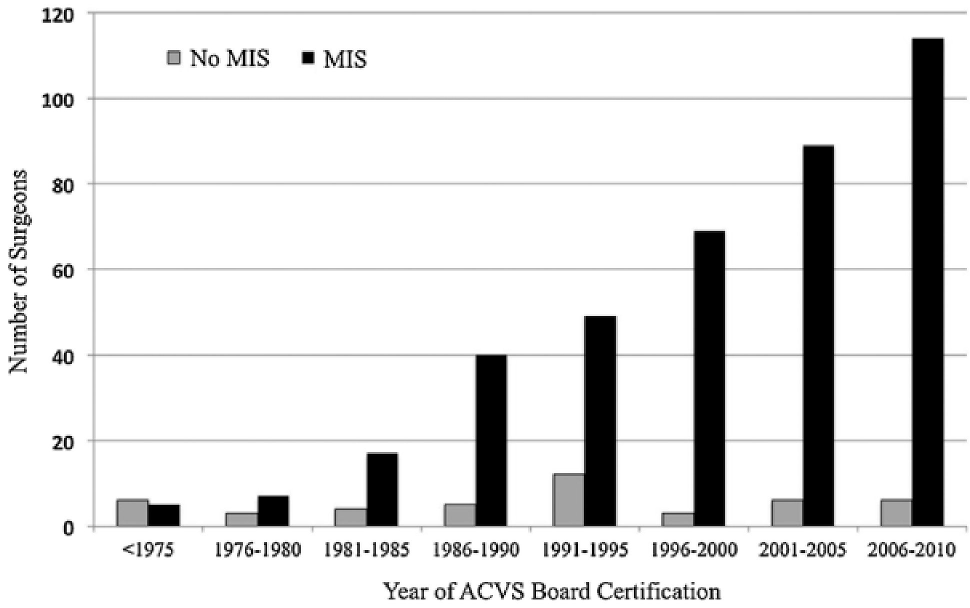

Figure 1. Adoption of minimally invasive surgery (MIS) among American College of Veterinary Surgeons (ACVS) diplomates according to year of board certification (1975–2010) (Bleedorn et al., 2013).

2.2 OPERATIVE TECHNIQUE AND APPLICATIONS OF LAPAROSCOPY

2.2.1 TECHNIQUE

Laparoscopy is a minimally invasive surgical technique that provides direct visualization of the abdominal cavity's internal structures (Vieira de Almeida et al., 2003).The procedure involves creating a pneumoperitoneum by insufflating gas into the peritoneal cavity, followed by the insertion of a rigid telescope (laparoscope) through a portal in the abdominal wall (Carraretto et al., 2005; Chamness, 2005; Milech et al., 2021; Srivastava & Niranjan, 2010).Additional instruments, such as biopsy forceps or specialized surgical tools, can be introduced through adjacent ports to perform various diagnostic or therapeutic interventions (Chamness, 2005).

A room with adjustable lighting is desirable to allow laparoscopy to be performed in a dimly lit room to make visualization of the video monitor easier (Figure 2) (Brandão & Chamness, 2022).

Figure 2. Surgical suite adapted for laparoscopic procedures, illustrating a dedicated endoscopy tower and controlled lighting conditions. Courtesy of Hospital Veterinário de São Bento (H.V.S.B.).

Dry CO_2 (0-0.5% relative humidity) at 20-25°C is the most commonly used gas for establishing pneumoperitoneum, a practice referred to as capnoperitoneum (Gibson et al., 2021; Milech et al., 2021). Carbon dioxide is delivered from gas tanks to the patient via a mechanical insufflator connected through a hose and introduced into the peritoneal cavity using a cannula. The insufflator facilitates the monitoring and maintenance of intra-abdominal pressure (IAP), typically maintained around 8 to 10 mmHg, to provide adequate working space while minimizing physiological disturbances (Mayhew, 2011; Twedt & Monnet, 2005). This IAP level is generally recommended in veterinary practice for canine patients (Scott et al., 2020).

The insufflator automatically controls CO_2 flow rate and pressure throughout the procedure. For small animal MIS it is rarely suggested to use a flow over 2.5 $L \cdot min^{-1}$ (Brandão & Chamness, 2022).

2.2.2 CLINICAL APPLICATIONS

Laparoscopy is widely used in veterinary medicine for both diagnostic and therapeutic purposes. Table 1 summarizes the most common laparoscopic procedures performed in small animal practice, including diagnostic evaluations and surgical interventions (Duke et al., 1996; Milovancev & Townsend, 2015; Twedt & Monnet, 2005).

Table 1. Common laparoscopic procedures in small animal veterinary practice. Adapted from Duke et al. (1996), Milovancev and Townsend (2015) and Twedt and Monnet (2005).

Diagnostic	Surgical
Adrenal evaluation	Adrenalectomy
Cholecystocentesis	Artificial urethral sphincter placement
Intestinal biopsy	Cholecystectomy
Kidney biopsy	Cryptorchid surgery
Liver biopsy	Cystoscopy
Pancreatic biopsy	Feeding tube placement
Reproductive evaluation	Gastric foreign body removal
Splenic evaluation	Gastropexy
	Ovariectomy
	Ovariohysterectomy
	Splenectomy
	Ureteronephrectomy

2.3 THERAPEUTIC BENEFITS, POTENTIAL CONSTRAITS, AND CONTRAINDICATIONS OF VETERINARY LAPAROSCOPY

Laparoscopy is widely regarded as a safe and effective surgical technique, associated with a low incidence of complications (Twedt & Monnet, 2005). However, it is crucial to recognize that MIS still requires significant expertise and carries inherent risks (Dec & Andruszkiewicz, 2015).

2.3.1 ADVANTAGES

Laparoscopy offers several advantages over traditional open surgical approaches. These benefits include reduced postoperative pain (Devitt et al., 2005; Srivastava & Niranjan, 2010), faster return to normal function (Culp et al., 2009; Srivastava & Niranjan, 2010), lower rates of surgical site infections (Hayden & Cowman, 2011; Mayhew, 2011), and shorter hospitalization periods (Lee & Choi, 2015; Mayhew, 2011). Additional advantages encompass decreased adhesion formation (Gutt et al., 2004), shorter healing times, improved cosmetic outcomes, and reduced levels of inflammatory mediators and cells (Hayden & Cowman, 2011; Özdemir-van Brunschot et al., 2016).

2.3.2 LIMITATIONS AND POTENTIAL COMPLICATIONS

While laparoscopic surgery offers numerous advantages over traditional open approaches, it is not without limitations and potential complications. Anesthetists must account for physiological changes induced by gas insufflation into the abdomen, particularly concerning the cardiovascular and respiratory systems (Hayden & Cowman, 2011; Van Goethem & Katic, 2021).

Complications during access to the abdominal cavity have been reported in several clinical studies within small animal medicine, including subcutaneous emphysema, fatal gas embolism, and splenic injury (Twedt & Monnet, 2005). Entry-related complications are inherent to all laparoscopic procedures and represent the most commonly reported procedural complications (Koivusalo & Lindgren, 2000a; Twedt & Monnet, 2005).

While the minimally invasive nature of laparoscopic surgery reduces peritoneal trauma, it introduces new elements into the abdominal cavity, such as increased IAP, insufflation gases, and alterations in temperature and humidity, all of which may affect peritoneal biology and integrity (Milech et al., 2021).

Conversion to laparotomy should not be viewed as a failure or complication but rather as a proactive measure to prevent intraoperative or postoperative complications. In veterinary medicine, conversion rates ranging from 0% to 30% have been reported (Twedt & Monnet, 2005).

Bradycardia and arrhythmias, as reported by Heyba et al. (2020), Myles (1991) and Yong et al. (2015) during gas insufflation are not necessarily benign and may act as early warning signs of impending cardiac arrest. These cardiovascular disturbances often arise in response to peritoneal stretch or vagal stimulation, and their occurrence—even in "fit and healthy" patients undergoing elective and general surgical procedures—

highlights the need for continuous and vigilant intraoperative monitoring (Heyba et al., 2020; Myles, 1991; Yong et al., 2015). This is particularly important because general anesthesia suppresses autonomic cardiovascular responses, reducing the patient's ability to compensate for sudden physiological changes. This is especially critical in individuals with limited physiological reserves, such as very small, geriatric, obese, or systemically compromised animals (Van Goethem & Katic, 2021).

In very small animals (less than 2 kg body weight), the available working space is significantly reduced, necessitating the use of miniature telescopes and surgical instruments (Culp et al., 2009; Twedt & Monnet, 2005; Van Goethem & Katic, 2021). Additionally, the presence of excessive intra-abdominal adipose tissue can obscure visualization of critical anatomical landmarks, increasing the technical difficulty and prolonging surgical time (Atkinson et al., 2017). These anatomical and morphological constraints, frequently encountered in specific breeds or body condition scores, underscore the importance of meticulous preoperative planning and individualized anesthetic and surgical strategies (Twedt & Monnet, 2005).

2.3.3 CONTRAINDICATIONS

Contraindications to laparoscopic surgery are generally classified as either absolute or relative. Absolute contraindications refer to conditions in which laparoscopy is clearly inadvisable, typically due to patient factors that preclude the use of pneumoperitoneum or the lack of essential equipment. Relative contraindications, on the other hand, may be overcome with appropriate perioperative strategies, allowing the benefits of MIS to outweigh potential risks (Dec & Andruszkiewicz, 2015).

Absolute contraindications include conditions such as diaphragmatic hernia, septic peritonitis, or clinical scenarios where open surgery is clearly indicated (Twedt & Monnet, 2005). These situations pose substantial risks that render laparoscopy inappropriate. Additionally, patients with severe cardiopulmonary instability may not tolerate the physiological changes induced by pneumoperitoneum, such as increased intra-abdominal pressure and CO_2 absorption, which can compromise cardiovascular and respiratory function (Hayden & Cowman, 2011).

Relative contraindications encompass a broader spectrum of factors that may increase the complexity or risk of the laparoscopic approach but do not necessarily preclude it. These include a history of previous abdominal surgery with suspected adhesions, large intra-abdominal masses, pregnancy, and coagulopathies (Table 2) (Van Goethem & Katic, 2021). In such cases, thorough preoperative evaluation, advanced imaging, and careful planning can help mitigate risks and guide surgical decision-making (Dec & Andruszkiewicz, 2015).

Table 2. Common contraindications and limitations for laparoscopic surgery in veterinary patients, categorised by origin (Van Goethem & Katic, 2021).

Category	Contraindications
Instrument-related	Lack of designated instruments
Operator-related	Insufficient training or experience
Patient-related	Hemodynamic instability
	Respiratory comorbidities
	Previous abdominal surgery/adhesion formation
Disease-related	Diaphragmatic hernia
	Large abdominal mass
	Septic peritonitis
	Intra-abdominal malignancy
	Increased intracranial pressure
	Pregnancy
	Portal hypertension and coagulopathies

It is important to recognize that the list of contraindications has evolved over time, reflecting growing surgical expertise and continuous advancements in laparoscopic equipment and techniques. Moreover, the experience of the surgeon and the availability of appropriate instrumentation play a pivotal role; lack of training or specialized tools may themselves represent practical limitations to laparoscopic procedures (Fransson et al., 2021).

2.4 PATHOPHYSIOLOGY OF PNEUMOPERITONEUM

Laparoscopic surgery is associated with significant alterations in both haemodynamic and respiratory physiology, even in otherwise healthy individuals

(Srivastava & Niranjan, 2010). These changes can become clinically significant in patients with pre-existing cardiopulmonary compromise, increasing the risk of perioperative complications (Odeberg-Wernerman, 2000). Multiple intraoperative factors contribute to the extent and nature of these physiological effects, acting either independently or synergistically. Key variables include:

- The type of insufflation gas used;
- The establishment and maintenance of pneumoperitoneum;
- The level of intra-abdominal pressure (IAP);
- Patient positioning during surgery (Mama & de Rezende, 2015; Odeberg-Wernerman, 2000).

2.4.1 HAEMODYNAMICS EFFECTS

The haemodynamic consequences of pneumoperitoneum (PNP) are dynamic and phase-dependent, evolving throughout the key stages of laparoscopic surgery, including induction of anaesthesia, abdominal insufflation, maintenance of pneumoperitoneum, desufflation, and recovery. These changes result from complex interactions between systemic vascular resistance (SVR), cardiac output (CO), mean arterial pressure (MAP), and other cardiovascular parameters (Figure 3). Understanding these sequential variations supports more accurate cardiovascular monitoring and timely therapeutic interventions during laparoscopic procedures (Atkinson et al., 2017)**.**

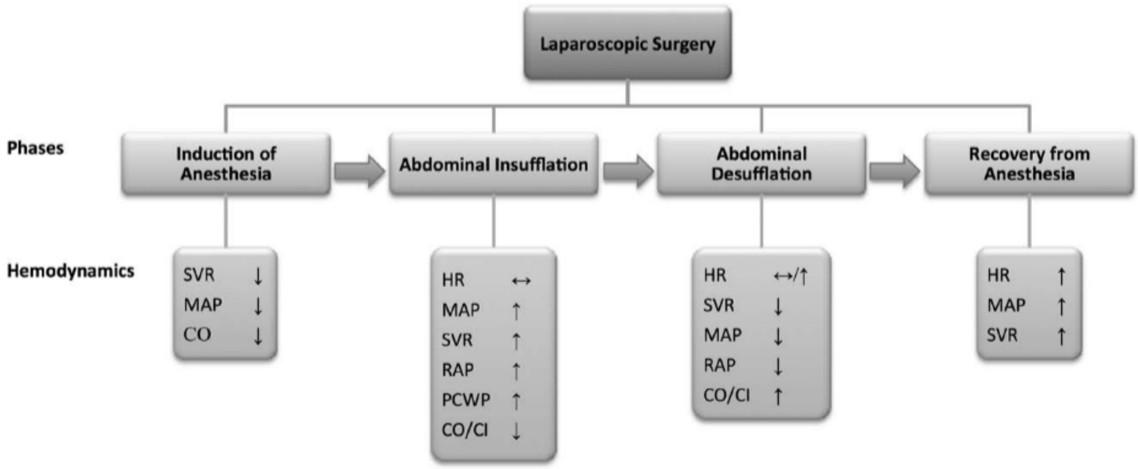

Figure 3. Sequential haemodynamic changes across the main phases of laparoscopic surgery, illustrating typical cardiovascular responses to pneumoperitoneum and desufflation (Atkinson et al., 2017). Abbreviations: CI, cardiac index; CO, cardiac output; HR, heart rate; MAP, mean arterial pressure;

PCWP, pulmonary capillary wedge pressure; RAP, right atrial pressure; SVR, systemic vascular resistance.

2.4.1.1 INSUFFLATION GAS CHOICES

The selection of an appropriate insufflation gas is critical in laparoscopic surgery, as it significantly influences procedural safety and clinical outcomes. An ideal gas should exhibit minimal peritoneal absorption, limited physiological effects, rapid elimination, non-combustibility, low risk of adverse effects from intravascular embolization, and high solubility in blood to facilitate swift clearance (Gerges et al., 2006).

Carbon dioxide remains the standard insufflation gas due to its high solubility in blood, allowing efficient absorption and pulmonary elimination, thereby minimizing embolic risks. Its non-flammable nature makes it suitable for procedures involving electrocautery or lasers. However, CO_2 insufflation can lead to physiological alterations, including acid–base disturbances and cardiopulmonary effects, necessitating vigilant intraoperative monitoring (Atkinson et al., 2017; Duke et al., 1996; Kaba & Joris, 2001; Koivusalo & Lindgren, 2000a).

Extraperitoneal CO_2 insufflation has been investigated as an alternative, with studies showing similar or greater elevations in end-tidal carbon dioxide ($EtCO_2$) and pulmonary CO_2 elimination compared to intraperitoneal insufflation. Maintaining normocapnia may require increased tidal volumes (VT) (Giebler et al., 1997). Hemodynamic responses vary, with some studies reporting unchanged MAP, suggesting different reflex mechanisms compared to intraperitoneal insufflation (Wright et al., 1995).

The conditioning of insufflation gas, specifically warming and humidifying CO_2, has been proposed to reduce peritoneal damage and postoperative pain. While some studies report benefits such as reduced pain and opioid requirements (Nguyen et al., 2002), others find no significant advantages in terms of postoperative pain or recovery times (Mouton et al., 1999). Notably, Milech et al. (2021) observed that heated CO_2 may increase inflammatory responses and reactive oxygen species (ROS) formation in canine models, raising concerns about its routine use (Milech et al., 2021).

Alternative gases such as helium (He), argon (Ar), nitrogen (N_2), and nitrous oxide (N_2O) have been explored. Helium, an inert gas, does not increase ventilation requirements but can elevate peak airway pressures and the alveolar-arterial oxygen gradient (A-a) (McMahon et al., 1993). While helium does not significantly affect arterial blood pressure, its low solubility raises concerns about gas embolism risks (Odeberg-Wernerman, 2000). Argon has been associated with increased SVR and decreased CO, suggesting potential hemodynamic disadvantages (Eisenhauer et al., 1994). Nitrous oxide, despite its anesthetic properties, supports combustion and has been linked to intraoperative explosions, limiting its use (Gerges et al., 2006).

Gasless laparoscopy, employing abdominal wall lift techniques, eliminates the need for insufflation gases, thereby avoiding associated cardiopulmonary effects (B. Fransson & Ragle, 2011; Jiang et al., 2021; Paolucci et al., 1995). Studies indicate that this method maintains hemodynamic stability and higher pulmonary compliance compared to CO_2 Pneumoperitoneum (Lindgren et al., 1995; Rademaker et al., 1995; Watkins et al., 2013). However, it may compromise surgical exposure and increase technical difficult (Odeberg-Wernerman, 2000).

2.4.1.1.1 EFFECTS OF CARBON DIOXIDE ABSORPTION

As mentioned in the previous subsection, CO_2 is rapidly absorbed across the peritoneal surface into the systemic circulation. This rapid diffusion leads to an elevation in arterial carbon dioxide tension ($PaCO_2$), resulting in systemic hypercapnia and respiratory acidosis if not counteracted by increased alveolar ventilation (Srivastava & Niranjan, 2010).

Systemic CO_2 accumulation triggers a complex cascade of neurohumoral and metabolic responses. Hypercapnia stimulates peripheral and central chemoreceptors, leading to sympathetic nervous system activation. This, in turn, promotes the release of vasopressin and catecholamines, and activates the renin–angiotensin–aldosterone system (RAAS). These pathways contribute to an increase in SVR and afterload, representing compensatory mechanisms aimed at preserving perfusion pressure (Atkinson et al., 2017; Mama & de Rezende, 2015; Özdemir-van Brunschot et al., 2016).

Simultaneously, hypercapnic acidosis exerts direct negative effects on myocardial function. It reduces myocardial contractility and enhances cardiac sensitivity to catecholamines, increasing the risk of arrhythmias. These cardiovascular effects are particularly significant in patients with limited cardiac reserve (Yong et al., 2015).

While CO_2 generally promotes systemic vasodilation, its regional effects may vary. For instance, splanchnic vasodilation has been reported during laparoscopic procedures (Kaba & Joris, 2001). Additionally, CO_2 has also been implicated in promoting oxidative stress, as demonstrated by alterations in oxidant–antioxidant balance in canine models exposed to prolonged hypercapnia (Lee & Choi, 2015).

Moreover, hypercapnia is associated with increased heart rate, myocardial depression, and coronary vasodilation, which can raise myocardial oxygen demand and affect oxygen delivery–consumption balance (Crystal, 2015). Although these effects are typically transient, their clinical impact can be significant in susceptible individuals (Zuckerman & Heneghan, 2002).

Residual CO_2 not eliminated during anesthesia continues to be excreted postoperatively. Notably, bone tissue acts as the largest physiological reservoir, contributing to delayed CO_2 clearance (Koivusalo & Lindgren, 2000a). Mealy et al. (1992) observed that hypercapnia may persist for several hours after surgery, underscoring the importance of continued monitoring and individualized respiratory support during recovery (Mealy et al., 1992).

2.4.1.2 LEVEL OF INTRA-ABDOMINAL PRESSURE

The intra-abdominal pressure (IAP) generated during laparoscopic procedures is a critical determinant of the systemic physiological response, influencing cardiovascular, respiratory, and renal function (Figure 4) (Atkinson et al., 2017; Ortenzi et al., 2022). Elevations in IAP are consistently associated with reductions in venous return, cardiac output, and splanchnic perfusion, together with increases in systemic vascular resistance (SVR) (Atkinson et al., 2017; Mama & de Rezende, 2015). While these alterations become more pronounced at IAP levels exceeding 12 mmHg, even moderate elevations can significantly disrupt homeostatic mechanisms, particularly in anesthetised patients (Koivusalo & Lindgren, 2000).

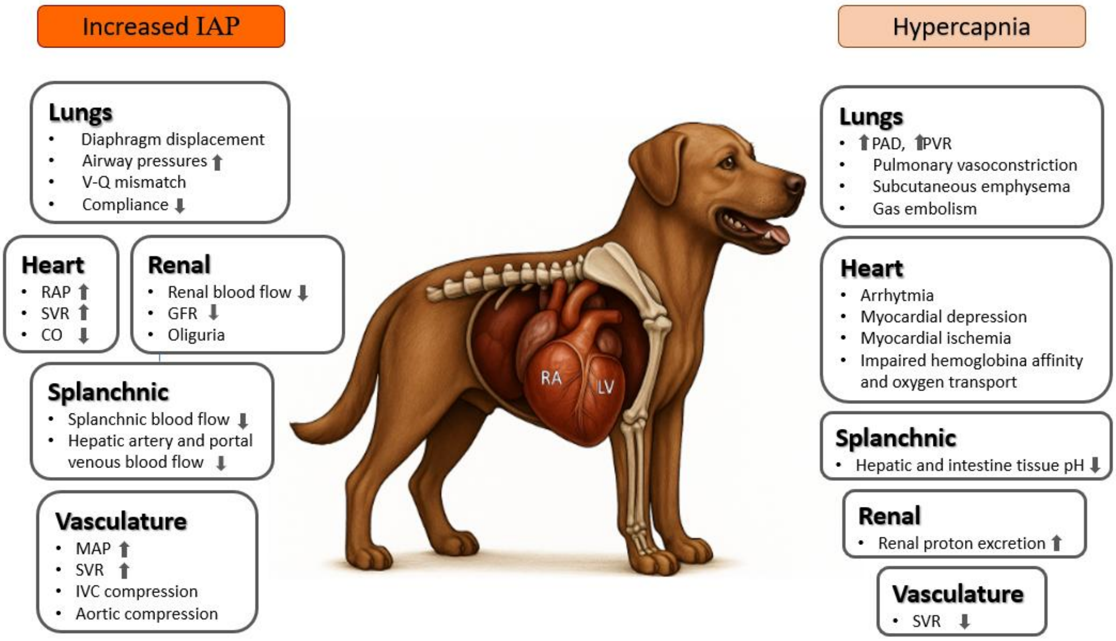

Figure 4. Systemic physiological effects of increased intra-abdominal pressure and hypercapnia during laparoscopic surgery. Adapted from Atkinson et al. (2017). Abbreviations: CO, cardiac output; GFR, glomerular filtration rate; IAP, intra-abdominal pressure; MAP, mean arterial pressure; PAP, pulmonary artery pressure; RAP, right atrial pressure; SVR, systemic vascular resistance.

2.4.1.2.1 CARDIOVASCULAR RESPONSES

The haemodynamic consequences of elevated IAP primarily stem from the mechanical compression of the inferior vena cava (IVC) and other major abdominal vessels. This compression reduces venous return, thereby decreasing preload, stroke volume (SV), and ultimately cardiac output (CO). In response, a compensatory increase in SVR occurs, which may transiently preserve or even increase MAP, particularly in normovolemic individuals (Koivusalo & Lindgren, 2000). However, this apparent stability may mask significant regional hypoperfusion, particularly affecting abdominal organs (Yong et al., 2015).

Both experimental and clinical studies confirm that IAP levels between 10 and 15 mmHg significantly reduce blood flow to critical visceral organs. In dogs, IAP above 12 mmHg has been shown to reduce superior mesenteric and portal vein flow by approximately 24% (Mama & de Rezende, 2015). In humans, an increase from 10 mmHg to 15 mmHg reduces organ perfusion by 54% to the stomach, 32% to the jejunum, 11% to the duodenum, 4% to the colon, 39% to the liver, and 60% to the parietal peritoneum (Koivusalo & Lindgren, 2000).

To mitigate these effects, it is recommended to maintain IAP at or below 10 mmHg, particularly in cardiovascularly compromised or high-risk patients. Surpassing physiological portal pressures (7–10 mmHg) can severely compromise splanchnic perfusion and increase the risk of ischemia-reperfusion injury and oxidative stress, which may persist even after desufflation (Lee & Choi, 2015).

Furthermore, elevated IAP has been shown to decrease femoral venous flow, promoting venous stasis and potentially increasing the risk of deep vein thrombosis. Despite this, current evidence does not suggest a significantly higher incidence of thromboembolic events in laparoscopic procedures compared to open surgery (Kaba & Joris, 2001).

2.4.1.2.2 RENAL FUNCTION AND NEUROHORMONAL REGULATION

Renal dysfunction is a well-established consequence of elevated IAP during laparoscopic procedures, affecting renal perfusion and glomerular filtration even in adequately volume-resuscitated patients (Koivusalo & Lindgren, 2000; Mama & de Rezende, 2015). These alterations arise primarily from a combination of mechanical compression and neurohormonal responses that compromise renal blood flow and filtration efficiency (Atkinson et al., 2017; Vieira de Almeida & Marisa Ganem, 2004).

Mechanically, increased IAP compresses the renal parenchyma, arteries, veins, and ureters, resulting in elevated renal vascular resistance and reduced glomerular filtration rate (GFR). For instance, an IAP between 15 and 20 mmHg may cause renal vascular resistance to increase by up to 555% and reduce GFR by approximately 25%, despite preserved intravascular volume (Koivusalo & Lindgren, 2000). In veterinary models, renal blood flow and filtration were shown to decrease by more than 75% in dogs at an IAP of 20 mmHg, with complete anuria observed at 40 mmHg (Mama & de Rezende, 2015).

The haemodynamic impairment associated with IAP persists even after desufflation, as experimental studies demonstrated that renal vein outflow may remain reduced for at least two hours postoperatively (Atkinson et al., 2017; Koivusalo & Lindgren, 2000). These findings highlight the risk of prolonged renal compromise, particularly in patients undergoing lengthy laparoscopic procedures or with pre-existing renal conditions (Mama & de Rezende, 2015).

Oliguria is frequently observed during laparoscopy, even in the absence of hypovolemia, reflecting the sensitivity of renal function to transient increases in IAP (Mama & de Rezende, 2015). This effect is not limited to hypotensive or volume-depleted states, as urine output may decline even under normovolemic, anesthetized conditions due to reduced renal perfusion (Atkinson et al., 2017).

Neurohormonal responses further exacerbate renal dysfunction during pneumoperitoneum. A key pathway is the activation of the RAAS, triggered by elevated IAP and reduced renal perfusion pressure (Vieira de Almeida & Marisa Ganem, 2004). Renin-angiotensin-aldosterone system activation promotes systemic vasoconstriction via angiotensin II, which redirects renal blood flow from the medulla to the cortex. While this may preserve superficial nephron perfusion, it significantly compromises medullary oxygenation and reduces overall GFR (Mama & de Rezende, 2015; Vieira de Almeida & Marisa Ganem, 2004).

Additionally, sympathetic nervous system activation contributes to arterial vasoconstriction and increased renal vascular tone, reinforcing the effects of RAAS on renal perfusion (Mama & de Rezende, 2015). These neurohumoral mechanisms act synergistically with mechanical compression to depress renal output and filtration during PNP (Atkinson et al., 2017).

To reduce the risk of renal compromise, adequate intravascular volume loading is recommended both prior to and throughout CO_2 insufflation, particularly in prolonged procedures or at higher IAP levels (Koivusalo & Lindgren, 2000).

2.4.1.2.3 LOW-PRESSURE PNEUMOPERITONEUM: EVIDENCE AND PRACTICAL CONSIDERATIONS

The optimal IAP for laparoscopic procedures remains a topic of ongoing discussion. However, most surgical societies—including the European Association for Endoscopic Surgery (EAES)—advocate the use of the lowest IAP that still allows for adequate exposure of the surgical field, rather than relying on fixed pressure values. This approach reflects growing awareness of the physiological burden imposed by pneumoperitoneum and the need to minimise its systemic impact (Neudecker et al., 2002).

Low-pressure pneumoperitoneum, commonly defined as an IAP between 6 and 10 mmHg, has been proposed as a strategy to mitigate the adverse haemodynamic, respiratory, and renal effects associated with higher insufflation pressures. Its feasibility and safety have been demonstrated in human clinical studies, particularly in laparoscopic cholecystectomy, where it has been shown to preserve cardiovascular stability—especially in patients with limited cardiac reserve (Dexter et al., 1999).

From a surgical standpoint, reduced IAP may compromise intra-abdominal visibility and increase the technical difficulty of tissue dissection. Nonetheless, multiple studies have reported clear clinical benefits, including less postoperative pain, lower analgesic requirements, improved preservation of pulmonary function, and shorter hospitalisation (Ortenzi et al., 2022; Pradyumna Joshipura et al., 2009). Rashdan et al. (2023) further support these findings, highlighting reduced inflammatory responses and significantly lower pain scores at six hours postoperatively in patients managed with low-pressure techniques (Rashdan et al., 2023). A systematic review by Brunschot et al. (2016) confirmed that low-pressure PNP significantly reduces postoperative pain, particularly on postoperative days two and three. While experimental data suggest that reduced IAP may attenuate hepatic and renal injury, these findings remain inconsistent in clinical translation, especially in healthy patients, and should be interpreted with caution (Özdemir-van Brunschot et al., 2016).

Despite these advantages, a trade-off exists between physiological benefit and surgical efficiency. Lower pressures may lead to longer operative times due to reduced visualisation of anatomical landmarks, potentially increasing procedural costs (Ortenzi et al., 2022; Özdemir-van Brunschot et al., 2016). However, systematic evaluations have shown that this does not correlate with increased complication rates or conversions to open surgery (Ortenzi et al., 2022).

In the context of veterinary surgery, the direct extrapolation of human data must be carefully considered. For instance, in dogs, the anatomical positioning of the inferior vena cava dorsal to the aorta may lead to earlier onset of venous compression during insufflation. This species-specific variation may increase susceptibility to haemodynamic compromise at IAPs still considered "safe" in human protocols (Odeberg-Wernerman, 2000; Richardson & Trinkle, 1976).

2.4.1.3 PATIENT POSITIONING

Patient positioning is a critical factor influencing both the efficacy of laparoscopic surgical procedures and the patient's haemodynamic and respiratory status. The anatomical redistribution of abdominal contents under gravitational influence can either facilitate or hinder surgical exposure, depending on the orientation applied. Accordingly, the choice of position must be adapted to the anatomical region targeted and the physiological status of the patient (Gibson et al., 2021; Gross et al., 2005).

The Trendelenburg position—where the patient is tilted with the head lower than the pelvis—is commonly used to displace abdominal organs cranially and enhance exposure of the pelvic region (Figure 5A). However, this position is associated with an increase in intrathoracic pressure and a reduction in functional residual capacity, resulting in diminished lung volumes, increased airway resistance, and potentially impaired ventilation and oxygenation (Atkinson et al., 2017; Srivastava & Niranjan, 2010).

Conversely, the reverse Trendelenburg position facilitates caudal displacement of abdominal viscera, potentially improving diaphragmatic excursion and pulmonary function by decreasing diaphragmatic compression (Figure 5B). Nonetheless, it may impair venous return and predispose to hypotension due to gravitational pooling of blood in the lower extremities (Dec & Andruszkiewicz, 2015).

Clinical studies in human medicine suggest that tilting patients beyond 15° in either Trendelenburg or reverse Trendelenburg can lead to marked cardiovascular alterations, including reduced cardiac output (CO), decreased stroke volume (SV), and compensatory tachycardia. These changes are primarily attributed to impaired venous return and vascular distension. For most procedures, a 10° tilt in either direction is generally sufficient to optimize the surgical field without significantly compromising haemodynamic stability (Gibson et al., 2021).

In veterinary medicine, a study by Park & Okano (2015) demonstrated that pneumoperitoneum induces significant respiratory and cardiovascular changes in dogs, with the most pronounced effects observed in the Trendelenburg position, followed by the reverse Trendelenburg (Park & Okano, 2015).

Although deep vein thrombosis (DVT) is rare in small animal patients, venous stasis during prolonged procedures may theoretically increase thrombotic risk. While mechanical prophylaxis (e.g., compression devices) is standard in human surgery, such measures are rarely used in veterinary practice. Nonetheless, awareness of positional haemodynamic compromise remains essential (Dec & Andruszkiewicz, 2015; Gibson et al., 2021).

In small animals, anatomical differences such as lateral abdominal flattening make lateral tilting particularly valuable. Operating tables with lateral tilt functionality (±10° to 30°) significantly improve access to lateralized organs and quadrants. However, the cost and availability of these adjustable systems may pose limitations in some clinical settings (Gibson et al., 2021).

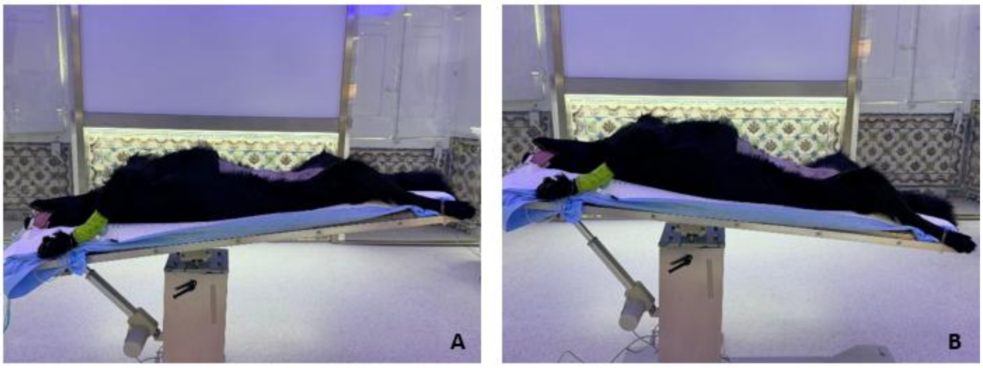

Figure 5. Trendelenburg position (A) and reverse Trendelenburg position (B). Courtesy of Hospital Veterinário de São Bento (H.V.S.B.).

Ultimately, the optimal patient position should be selected based on the surgical target, surgeon experience, and the physiological tolerance of the patient. Any positional changes must be performed gradually to minimize abrupt haemodynamic fluctuations. Re-evaluation of endotracheal tube placement after repositioning is strongly recommended to ensure airway patency and effective ventilation (Kaba & Joris, 2001).

2.4.2 RESPIRATORY EFFECTS AND PULMONARY MECHANICS

Respiratory alterations during PNP encompass significant changes in pulmonary mechanics, gas exchange, and acid-base homeostasis (Kaba & Joris, 2001; Koivusalo & Lindgren, 2000). These modifications may be particularly pronounced in small animals, where thoracic conformation can substantially influence ventilatory dynamics during laparoscopic surgery (Srivastava & Niranjan, 2010; Xu et al., 2025).

The insufflation of CO_2 into the abdominal cavity increases IAP, leading to cranial displacement of the diaphragm and mechanical compression of the lower lung lobes (Neudecker et al., 2002; Özdemir-van Brunschot et al., 2016). This displacement compromises diaphragmatic excursion and reduces overall pulmonary compliance, an effect that is exacerbated by neuromuscular blockade and anesthesia-induced muscle relaxation (Dec & Andruszkiewicz, 2015; Fahy et al., 1995). The resulting mechanical impedance raises airway pressures, including peak and plateau pressures, and restricts tidal volume (VT), ultimately impairing respiratory efficiency (Özdemir-van Brunschot et al., 2016).

Quantitatively, dynamic pulmonary compliance (Cdyn) may decrease by 30% to 50% even in healthy individuals under controlled ventilation, a change directly correlated with increased IAP (Kaba & Joris, 2001). Although these effects are largely reversible upon desufflation, their intraoperative impact is clinically significant and demands careful monitoring, particularly in patients with limited pulmonary reserve (Koivusalo & Lindgren, 2000).

Patient positioning can further influence respiratory function during PNP. Trendelenburg and reverse Trendelenburg positions, often required during laparoscopic procedures, have been shown to decrease compliance due to gravitational shifts of abdominal contents toward the thorax, thereby amplifying intrathoracic pressure (Hirvonen et al., 1995; Oikkonen & Tallgren, 1995). Obeid et al. (1995) demonstrated a progressive decline in Cdyn with rising IAP across different body positions—including supine, head-up, and head-down orientations—emphasizing that both pneumoperitoneum and patient orientation are key modulators of respiratory mechanics (Obeid et al., 1995).

These mechanical constraints are associated with reductions in functional residual capacity (FRC), total lung capacity (TLC), and vital capacity (VC), creating a predisposition to intraoperative atelectasis and impaired alveolar gas exchange. These pathophysiological changes are particularly relevant in small animal patients, where thoracic morphology (e.g., brachycephalic vs. dolichocephalic) may further modulate susceptibility to volume-related atelectasis and increased airway resistance (Srivastava & Niranjan, 2010).

To better understand the implications of these volumetric alterations, the main lung volumes and capacities are summarised in table 3, including their abbreviations and physiological definitions (Farry, 2022a; Rozanski & Hoffman, 2004).

Given these risks, continuous monitoring of airway pressures and pulmonary compliance is critical to detect early signs of barotrauma or ventilatory insufficiency (Dec & Andruszkiewicz, 2015; Neudecker et al., 2002; Xu et al., 2025).

Table 3. **Pulmonary volumes and capacities: terminology and physiological definitions.** Adapted from Farry (2022) and Rozanski and Hoffman (2004).

Term and Abbreviation	Definition
Tidal volume (VT)	Amount of air exchanged during normal respiration (air inhaled and exhaled in one breath)
Inspiratory capacity (IC)	Amount of air that can be inhaled starting from the end of a normal expiration (VT + IRV)
Inspiratory reserve volume (IRV)	Amount of air inspired over the tidal volume (extra amount that could be inhaled after normal inspiration)
Expiratory reserve volume (ERV)	Amount of air expired over the tidal volume (extra amount that could be exhaled after normal expiration)
Residual volume (RV)	Air remaining in the lungs after a forced expiration (amount of air trapped in alveoli)
Functional residual capacity (FRC)	Amount of air remaining in the lungs after a normal respiration (ERV + RV)
Vital capacity (VC)	Largest amount of air that can be moved in the lungs (VT + IRV + ERV)
Total lung capacity (TLC)	Maximum volume to which the lungs can be expanded (VT + ERV + RV)

2.4.2.1 OXYGENATION AND VENTILATION-PERFUSION MATCHING

Ventilation–perfusion matching (V/Q) describes the physiological relationship between alveolar ventilation and pulmonary perfusion, which is essential for effective gas exchange. In healthy individuals, gravity and thoracic geometry create a mild V/Q gradient that favors dependent lung regions. However, this balance is easily disrupted under general anesthesia and further altered during laparoscopic procedures involving CO_2 pneumoperitoneum (Haskins, 2015).

As previously mentioned, the cephalad displacement of the diaphragm during PNP compresses basal lung regions, reducing functional residual capacity (FRC) and promoting regional atelectasis. This leads to ventilation–perfusion (V/Q) mismatch, as perfused areas of the lung receive insufficient ventilation, contributing to intrapulmonary shunting. The result is a widened alveolar–arterial (A–a) oxygen gradient and, in some cases, transient hypoxemia (Andersson et al., 2002; Atashkhoei et al., 2020; Carraretto et al., 2005; Dec & Andruszkiewicz, 2015; Hayden & Cowman, 2011).

Low V/Q units may also arise from bronchospasm, fluid accumulation, or epithelial edema, which compromise alveolar ventilation. In these regions, deoxygenated blood mixes with better-oxygenated blood from adequately ventilated areas—a hallmark of V/Q mismatch (Haskins, 2015).

Despite these changes, oxygen consumption remains stable, and oxygenation may paradoxically improve during the early phase of PNP. This effect has been attributed to increased intrathoracic pressure acting as intrinsic positive end-expiratory pressure (PEEPI), temporarily promoting alveolar recruitment and enhancing gas exchange (Magno et al., 1979; Odeberg S. & Sollevi, 1995). However, this benefit appears to be transient. Andersson et al. (2002) observed an initial reduction in pulmonary shunting after insufflation, which diminished after 30 minutes of sustained PNP (Andersson et al., 2002).

To maintain alveolar stability and prevent hypoxemia, the use of extrinsic positive end-expiratory pressure (PEEPE) has proven effective. When appropriately titrated, it improves V/Q matching and enhances arterial oxygenation, especially in patients with reduced pulmonary reserve or altered thoracic mechanics (Dec & Andruszkiewicz, 2015; Srivastava & Niranjan, 2010).

2.4.2.2 INFLUENCE OF THORACIC CONFORMATION ON RESPIRATORY MECHANICS

Thoracic conformation exerts a pivotal influence on respiratory function during laparoscopic surgery, particularly under general anesthesia and mechanical ventilation. Variations in thoracic shape—especially in terms of depth, width, and configuration—directly affect lung compliance, diaphragmatic mobility, chest wall impedance, and regional ventilation distribution. These morphological characteristics play a significant role in determining how individual patients tolerate increased IAP during PNP (Carraretto et al., 2005; Fahy et al., 1995; Xu et al., 2025).

In dolichomorphic (deep-chested) animals, the increased vertical thoracic dimension is associated with higher lung volumes but also with greater susceptibility to reduction in FRC when the diaphragm is displaced cranially by insufflation. This may predispose these patients to atelectasis and ventilation–perfusion (V/Q) mismatch during laparoscopy (Fahy et al., 1995).

In contrast, brachymorphic (barrel-chested) animals exhibit increased chest wall impedance and limited diaphragmatic excursion due to a broader, shallower thoracic cavity. This conformation can lead to uneven ventilation and a predisposition to regional hyperinflation, particularly under non-adaptive ventilation strategies. In these cases, dynamic adjustment of ventilatory parameters, informed by real-time monitoring of compliance and resistance, is essential to avoid overdistension and minimize the risk of ventilator-induced lung injury (Carraretto et al., 2005).

Surgical positioning (e.g., dorsal recumbency or Trendelenburg tilt) further exacerbates the effects of thoracic morphology on respiratory function by increasing thoracic impedance and altering transpulmonary pressure gradients. These changes may impair venous return and contribute to hemodynamic instability, particularly in morphotypes with reduced chest wall compliance (Fahy et al., 1995).

Importantly, body size interacts with thoracic conformation to further influence respiratory dynamics. Smaller dogs show greater relative variation in thoracic and pulmonary cross-sectional areas during tidal breathing, requiring more frequent intraoperative ventilatory adjustments to maintain effective gas exchange (Chan et al., 2017). Culp et al. (2009), in a comparative study on laparoscopic versus open ovariectomy in small dogs (<10 kg), reported enhanced postoperative recovery in the laparoscopic group, reinforcing the tolerance of this approach even in small-sized patients (Culp et al., 2009).

2.4.2.3 CLASSIFICATION OF THORACIC CONFORMATION

Thoracic conformation in dogs has been extensively characterized in various branches of veterinary medicine, particularly in cardiology and diagnostic imaging. In cardiology, thoracic shape is a critical parameter for interpreting vertebral heart scores and assessing breed-related variation in cardiac silhouette (Buchanan & Bücheler, 1995). In thoracic imaging, it provides a basis for understanding anatomical diversity across canine breeds and body types (Mateos Pañero et al., 2021; Santilli et al., 2019).

Several objective classification methods have been developed to quantify thoracic morphology, most commonly using morphometric ratios such as the thoracic depth-to-width ratio (TD/TW) and thoracic index (TI). These measurements allow for the categorization of dogs into thoracic types—typically classified as brachythoracic, mesothoracic, or dolichothoracic—based on dimensional relationships obtained from radiographic or physical examination (Barboza Filho et al., 2021; Soeratanapant et al., 2024).

These classification systems provide a standardized approach for comparing thoracic morphology across individuals and breeds, which is particularly relevant in anesthesia, respiratory monitoring, and surgical planning (Carraretto et al., 2005; Fahy et al., 1995). Notably, variations in thoracic geometry have been associated with differences in baseline lung compliance and ventilatory efficiency, factors that may influence respiratory management under general anesthesia (Fahy et al., 1995).

Although the direct impact of thoracic conformation on respiratory mechanics during PNP remains insufficiently caracterized, current knowledge on the mechanical effects of IAP suggests that thoracic shape may influence diaphragmatic displacement and airway resistance (Dec & Andruszkiewicz, 2015; Srivastava & Niranjan, 2010).

The subsections below describe the main approaches to thoracic classification currently used in veterinary medicine, including radiographic indices, clinical morphometry, and empirical visual assessment methods.

2.4.2.3.1 DEPTH-TO-WIDTH RATIO – RADIOGRAPHIC AND COMPUTED TOMOGRAPHY- BASED METHODS

The most widely accepted and repeatable method is based on the thoracic depth-to-width ratio (TD/TW). This approach, first systematically described by Buchanan & Bücheler (1995), is highly reproducible and easily applicable to radiographic imaging (Buchanan & Bücheler, 1995).

- Thoracic width (TW) is measured on dorsoventral (DV) or ventrodorsal (VD) projections as the distance between the medial borders of the eighth ribs at their most lateral curvatures (Figure 6A).

- **Thoracic depth (TD)** is measured on a lateral radiograph from the cranial edge of the xiphoid process to the ventral border of the vertebral column, along a line perpendicular to the spine (Figure 6B).

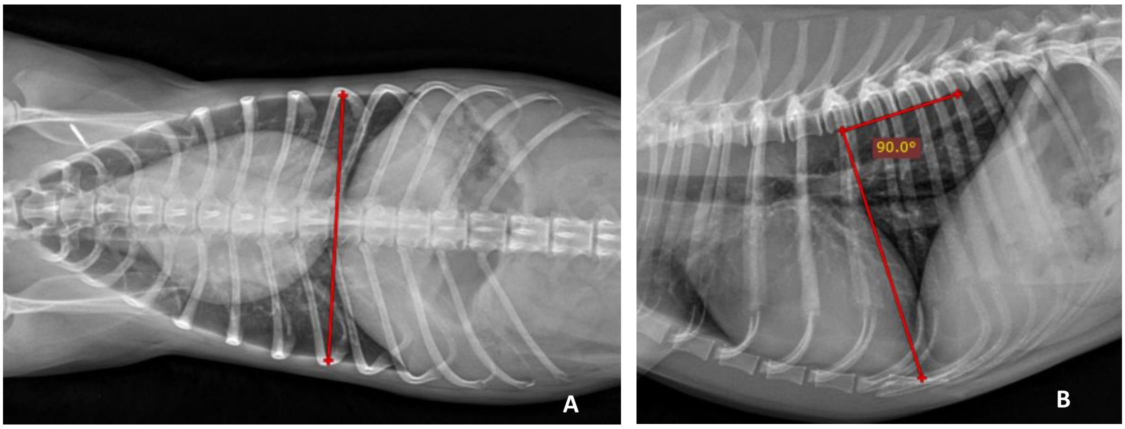

Figure 6. Radiographic measurement of thoracic width (A) and thoracic depth (B) used to calculate the thoracic depth-to-width (TD/TW) ratio, as described by Buchanan and Bücheler (1995). Courtesy of H.V.S.B.

Based on the TD/TW ratio, animals are classified as:

I. Dolichomorphic (deep-chested): TD/TW ≥ 1.25
II. Mesomorphic (intermediate): TD/TW = 0.75–1.25
III. Brachymorphic (broad-chested): TD/TW ≤ 0.75

This method has been validated and widely applied in cardiology and thoracic morphology studies. It provides a reliable anatomical basis for predicting how thoracic shape may influence lung compliance and diaphragmatic excursion (Barboza Filho et al., 2021; Buchanan, 2000; Buchanan & Bücheler, 1995).

With the advancement of diagnostic imaging, the same principle has been applied to computed tomography (CT) (Figure 7). In the CT-based adaptation, TD is measured in the sagittal plane from the xiphoid process to the ventral border of the vertebral column, while TW is measured in the dorsal plane across the widest internal point between the eighth ribs. The TD/TW threshold values remain the same (Soeratanapant et al., 2024).

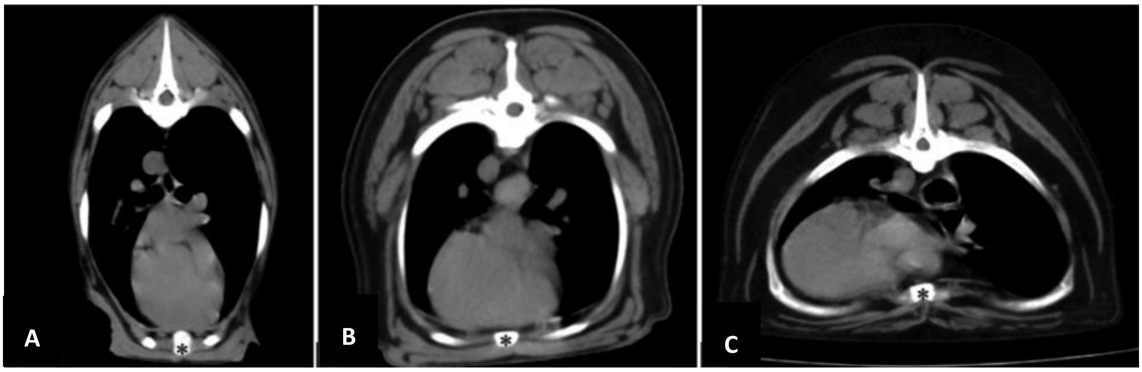

Figure 7. Transverse computed tomography (CT) images illustrating canine dolichomorphic (A), mesomorphic (B), and brachymorphic (C) thoracic conformations based on the thoracic depth-to-width (TD/TW) ratio (Soeratanapant et al., 2024). Asterisks (*) indicate the sternum.

2.4.2.3.2 THORACIC INDEX – CLINICAL MORPHOMETRY

Another objective and accessible method for thoracic classification is the Thorax Index (TI), which evaluates the relationship between thoracic width and depth as a percentage: TI = (thoracic width [cm] × 100) / thoracic depth [cm].

This measurement is typically obtained using a thoracic caliper in standing animals. As described by Pañero (2021) and Santilli (2019), TI ranges define conformation as follows:

I. Brachymorphic: TI = 90–100
II. Mesomorphic: TI = 60–89
III. Dolichomorphic: TI = 50–59 (Mateos Pañero et al., 2021; Santilli et al., 2019).

This method is simple and non-invasive, and has been used in clinical morphometry studies, particularly when radiographic equipment is unavailable. It provides a practical tool for classifying thoracic type, although body condition score and patient cooperation may introduce variability (Mateos Pañero et al., 2021).

2.4.2.3.3 VISUAL AND EMPIRICAL CLASSIFICATION METHODS

In settings where imaging or caliper-based morphometry is not feasible, some studies have used visual or empirical assessment of thoracic conformation. These methods rely on external inspection or subjective interpretation of thoracic proportions, either in physical examination or based on available imaging (Asorey et al., 2020; Corcoran, 1991).

Dogs are typically classified as:

I. Barrel-chested: broad chest at the sternum with a rounded thoracic cross-section
II. Deep-chested: narrow sternum and vertically elongated thorax
III. Intermediate-chested: morphology between the two extremes (Asorey et al., 2020).

This classification is often used in retrospective studies, where objective data are lacking. However, its subjective nature may lead to misclassification, particularly in mixed-breed dogs. As noted by Asorey et al. (2020) and Phansangiemjit et al. (2024)**,** radiographic confirmation is preferable whenever possible to ensure accurate grouping (Asorey et al., 2020; Phansangiemjit et al., 2024).

2.5 VENTILATORY STRATEGIES AND SPECIFIC ANESTHETIC PROTOCOLS

Laparoscopic surgery introduces a unique set of anesthetic and ventilatory challenges, primarily related to pneumoperitoneum, carbon dioxide absorption, and the frequent use of non-physiological patient positioning. These factors can significantly alter respiratory mechanics and cardiovascular dynamics, demanding specific perioperative strategies to mitigate physiological compromise (Mama & de Rezende, 2015; Srivastava & Niranjan, 2010). While the fundamental goals of anesthesia remain constant, the anesthetic plan must be adapted to the requirements of minimally invasive abdominal surgery (Srivastava & Niranjan, 2010).

In this context, anesthetic protocols must be designed to ensure effective ventilation, stable haemodynamics, and smooth recovery. The increasing prevalence of outpatient laparoscopic procedures has further emphasized the importance of short-acting drugs, rapid emergence, and minimization of postoperative discomfort (Gerges et al., 2006). Coordination between the surgical and anesthetic teams, along with thorough preoperative planning—including patient positioning, airway security, and monitoring setup—is essential to optimize outcomes and minimize risks (Dec & Andruszkiewicz, 2015).

2.5.1 GENERAL ANESTHESIA FOR LAPAROSCOPY

General anesthesia in veterinary medicine is a reversible pharmacological state designed to ensure unconsciousness, amnesia, analgesia, and muscle relaxation while maintaining thermoregulatory, cardiovascular, respiratory, hepatic, renal, and neurologic function (Brown et al., 2018; Kaba & Joris, 2001; Mama & de Rezende, 2015). In the context of laparoscopic procedures, it is considered the standard of care due to the physiological stress associated with PNP, the potential for significant postural changes, and the discomfort caused by intra-abdominal insufflation (Cunningham, 1998; Hayden & Cowman, 2011).

Achieving a safe and effective anesthetic plan requires an individualized approach that considers species-specific physiology, thoracic conformation, comorbidities, and the anticipated impact of increased IAP (Dec & Andruszkiewicz, 2015; Mama & de Rezende, 2015).

In elective procedures involving healthy animals, the anesthetic protocol typically begins with the administration of an opioid—often combined with a sedative or tranquilizer—to provide pre-emptive analgesia and anxiolysis. Dexmedetomidine, a commonly used α_2-agonist, offers sedative, analgesic, and sympatholytic effects, while also reducing anesthetic requirements, although its cardiovascular effects must be carefully monitored (Gerges et al., 2006). Anticholinergics may be included in selected cases to mitigate opioid-induced bradycardia or vagal reflexes during visceral manipulation (Gross et al., 2005; Mama & de Rezende, 2015).

A multimodal analgesic strategy is essential to minimize patient discomfort and improve perioperative outcomes. Intraoperative analgesia is commonly achieved using full μ-opioid agonists, such as fentanyl and methadone, administered as bolus injections or continuous infusions, depending on the intensity and duration of nociceptive stimuli. Lidocaine infusions and α_2-agonists serve as effective adjuvants, offering opioid-sparing effects and contributing to hemodynamic stability (Dec & Andruszkiewicz, 2015; Hayden & Cowman, 2011). Additional analgesic modalities—such as non-steroidal anti-inflammatory drugs (NSAIDs) when not contraindicated, local anesthetic techniques, and regional blocks—further enhance perioperative pain control (Dec & Andruszkiewicz, 2015; Mama & de Rezende, 2015).

Several regional anesthesia techniques may be employed as part of this multimodal approach, including the transversus abdominis plane (TAP) block, wound infiltration at portal sites, and intraperitoneal instillation of local anesthetics to address both somatic and visceral pain componentes (Dec & Andruszkiewicz, 2015; Hayden & Cowman, 2011; Portela et al., 2019). Liposomal bupivacaine, a long-acting formulation, offers extended analgesia and may further enhance recovery (Mama & de Rezende, 2015). In selected cases, particularly those involving prolonged procedures or significant visceral manipulation, epidural anesthesia can also be considered as a valuable adjunct (Srivastava & Niranjan, 2010).

For induction, agents such as propofol, alfaxalone, or ketamine are widely used due to their rapid onset and ease of titration. Propofol, in particular, offers favorable hemodynamic and antiemetic properties, although it may cause transient splenic enlargement, a consideration especially relevant in abdominal surgery (Mama & de Rezende, 2015). Once unconsciousness is achieved, endotracheal intubation is performed to secure the airway and facilitate mechanical ventilation, which is strongly recommended in laparoscopic surgery (Gross et al., 2005; Kaba & Joris, 2001). The use of supraglottic devices such as laryngeal mask airways (LMAs) is generally limited to brief procedures with low IAP and minimal repositioning (Srivastava & Niranjan, 2010).

Anesthesia is commonly maintained with volatile agents like isoflurane or sevoflurane, which offer rapid depth adjustment and predictable elimination. Isoflurane is often favored due to its lower arrhythmogenic and myocardial depressant effects (Srivastava & Niranjan, 2010). In some cases, total intravenous anesthesia (TIVA) protocols are adopted, particularly for patients with contraindications to inhalant use or for procedures requiring tight control of anesthetic depth (Dec & Andruszkiewicz, 2015).

Neuromuscular blockade is frequently required to ensure abdominal compliance and facilitate surgical exposure (Kaba & Joris, 2001). Short-acting non-depolarizing agents such as atracurium or vecuronium are preferred due to their reliable pharmacokinetics. Neuromuscular monitoring is essential throughout the procedure to avoid excessive or inadequate paralysis, and the use of reversal agents such as sugammadex allows for rapid and controlled emergence without the emetogenic risks associated with neostigmine (Dec & Andruszkiewicz, 2015).

Supportive care during anesthesia includes intravenous fluid administration to maintain vascular volume, counteract the vasodilatory effects of anesthetic agents, and compensate for the physiological effects of abdominal insufflation and positional changes on venous return and cardiac output (Mama & de Rezende, 2015). Hypotension, if observed, may require fluid boluses, reduction of anesthetic depth or IAP, or administration of inotropes such as dopamine or dobutamine (Kaba & Joris, 2001).

2.5.1.1 MECHANICAL VENTILATION AND MODE SELECTION

Mechanical ventilation (MV), or intermittent positive pressure ventilation (IPPV), is a cornerstone of anesthetic management in laparoscopic procedures due to the risk of hypoventilation, pulmonary atelectasis, and impaired gas exchange under general anesthesia (Fahy et al., 1995; Vegfors et al., 1994; Vieira de Almeida et al., 2003).

Among the available ventilatory strategies, volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) are the two most frequently employed modes in laparoscopic anesthesia (Atashkhoei et al., 2020; Carraretto et al., 2005; Dec & Andruszkiewicz, 2015; Fantoni et al., 2016). Their principal characteristics, advantages, and limitations are summarized in table 4 (Holbon, 2023).

Table 4. Comparison of pressure-controlled and volume-controlled ventilation modes (Holbon, 2023).

Types of ventilation	Advantages	Disadvantages
Volume-controlled ventilation (VCV)	- Ensures that tidal volume is maintained consistently throughout the ventilation, but the pressure generated on inspiration may vary (increase or decrease) with changes in the patient's thoracic or pulmonary compliance.	- Can be difficult to set an appropriate tidal volume accurately, especially in very small animals, meaning there is a risk of lung overinflation and consequent volutrauma. - In patients with low respiratory system compliance or high resistance to inspiratory flow, high inspiratory pressures may be attained. This can increase the risk of adverse cardiovascular effects and potential lung damage. Volume cycling ventilation is not considered a safe ventilator mode for patients with lung injury.
Pressure-controlled ventilation (PCV)	- Ensures that the pressure remains constant during ventilation but in this case, tidal volume may vary (increase or decrease) with changes in the patient's thoracic or pulmonary compliance. - Volutrauma is less likely, the pre-set pressure will prevent lung overinflation, and the airway pressure will be maintained throughout irrespective of changes in tidal volume. - The constant pressure throughout the inspiratory phase allows the alveoli to be kept open during the entire inspiratory time which maintains lung compliance and pulmonary gas exchange. - The use of pressure cycling ventilation in healthy patients resulted in higher pulmonary compliance and required lower inspiratory pressures when compared to volume cycling ventilation to achieve the same tidal volume.	- If compliance changes during ventilation, either increase or decrease will potentially result in either larger or smaller tidal volumes being delivered with consequent hyper or hypoventilation.

In the presence of pneumoperitoneum, the reduction in respiratory system compliance and the increase in airway resistance may result in elevated airway pressures when VCV is used, potentially increasing the risk of ventilator-induced lung injury (Carraretto et al., 2005; Fantoni et al., 2016). In contrast, PCV limits inspiratory airway pressure and provides a decelerating inspiratory flow pattern, which has been associated with improved alveolar recruitment and more homogeneous gas distribution during laparoscopic procedures (Dec & Andruszkiewicz, 2015; Fantoni et al., 2016).

Although tidal volume delivery during PCV is inherently dependent on dynamic changes in lung compliance and airway resistance, several studies have demonstrated more stable end-tidal CO_2 ($EtCO_2$) and arterial pH values under pneumoperitoneum when compared with VCV (Carraretto et al., 2005; Vieira de Almeida et al., 2003). Consequently, recent evidence supports a preferential use of PCV during laparoscopic procedures, particularly in obese or hypoventilated patients, due to its capacity to reduce peak airway pressures and improve oxygenation (Hayden & Cowman, 2011; Zitzmann et al., 2023). Nevertheless, ventilatory mode selection should remain individualized, taking into account patient-specific variables, surgical requirements, and equipment availability (Mama & de Rezende, 2015).

Once the ventilatory mode is selected, appropriate adjustments must be made to accommodate the physiological changes induced by PNP. It is not possible to accurately predict the ideal ventilator settings for every patient, but the choice of initial parameters is based on an understanding of the underlying pathophysiology. After connection to the ventilator, settings should be titrated to achieve normocapnia and adequate oxygenation with the lowest possible inspired oxygen fraction (FiO_2)(Haskins, 2015). Animals without pulmonary disease are expected to have compliant lungs and tolerate higher VT, lower positive end-expiratory pressure (PEEP), and lower airway pressures. Initially, FiO_2 of 100% is recommended for safety, and then it should be weaned to ≤60% after stabilization to minimize the risk of oxygen toxicity and absorption atelectasis (Hopper & Powell, 2013; Staffieri et al., 2007). Suggested starting values are summarized in Table 5 (Hopper, 2015).

Table 5. Suggested initial ventilator settings for patients with and without pulmonary disease (Hopper, 2015b).

Ventilator Parameter	Patient with Normal Lungs	Patient with Lung Disease
Fraction of inspired oxygen	100%	100%
Tidal volume ($mL \cdot kg^{-1}$)	8 to 12	6 to 8
Respiratory rate ($breaths \cdot min^{-1}$)	10 to 20	15 to 30
Minute ventilation ($mL \cdot kg^{-1} \cdot min^{-1}$)	150 to 250	100 to 250
Pressure above PEEP (cm H_2O)	8 to 10	10 to 15
Positive end-expiratory pressure (cm H_2O)	0 to 4	4 to 8
Inspiratory flow rate ($L \cdot min^{-1}$)	40 to 60	40 to 60
Inspiratory time (seconds)	0.8 to 1	0.8 to 1
Rise time (seconds)	0.1 to 0.5	0.1 to 0.5
Inspiratory-to-expiratory ratio	1:2	1:1 to 1:2
Inspiratory trigger	1 to 2 cm H_2O or 1 to 2 $L \cdot min^{-1}$	1 to 2 cm H_2O or 1 to 2 $L \cdot min^{-1}$

During pneumoperitoneum (PNP), minute ventilation (Vm) typically needs to be increased by 15–25% to maintain $EtCO_2$ within the target range of 35–40 mmHg, provided there is no excessive CO_2 retention or underlying pulmonary pathology such as emphysema (Gerges et al., 2006; Kaba & Joris, 2001; Srivastava & Niranjan, 2010).

Alveolar recruitment maneuvers (ARM) are advanced ventilatory strategies used to reopen collapsed alveoli and reverse anesthesia-induced atelectasis, especially after induction or PNP. These maneuvers temporarily apply sustained high airway pressures—typically 30 to 40 cm H_2O for 20 to 40 seconds—to raise transpulmonary pressure (PL) above the threshold needed to open non-aerated lung units (Di Bella et al., 2018; Staffieri et al., 2010). The primary objectives of ARM are to restore normal alveolar aeration, improve oxygenation, and increase overall respiratory system compliance. In dogs, the vital capacity maneuver has shown efficacy in re-expanding atelectatic areas and, when followed by maintenance PEEP (usually 5–10 cm H_2O), can sustain alveolar stability throughout surgery (Araos et al., 2022; Di Bella et al., 2018; García-Sanz et al., 2019).

2.5.2 POSTOPERATIVE MANAGEMENT: MULTIMODAL ANALGESIA AND NAUSEA CONTROL

Despite its minimally invasive nature, laparoscopy is not devoid of postoperative discomfort. Although pain is generally less intense and of shorter duration than after laparotomy, it can still be clinically significant, particularly during the first two hours post-procedure (Scott et al., 2020). Visceral pain often predominates due to peritoneal irritation and residual insufflation gas. This complication may be minimized by thoroughly evacuating intra-abdominal CO_2 at the end of surgery (Hayden & Cowman, 2011).

Effective perioperative analgesia is essential to facilitate early mobilization and reduce hospital stay. Pain management should begin preemptively and continue into the recovery period, with ongoing assessment using validated tools such as pain scales (Dec & Andruszkiewicz, 2015). As previously mentioned, a multimodal analgesic regimen is recommended, combining opioids, NSAIDs, and regional techniques to target different components of the nociceptive pathway. Tramadol may be particularly effective against visceral pain, while NSAIDs and paracetamol (where appropriate and species-specific) provide coverage for parietal and referred pain. This approach enhances analgesic efficacy while minimizing the dose and side effects of individual drugs (Gerges et al., 2006; Kaba & Joris, 2001).

Another important consideration following laparoscopy is postoperative nausea and vomiting (PONV), a frequently reported complication in both human and veterinary patients. Postoperative nausea and vomiting is attributed to peritoneal irritation, use of opioids, and residual CO_2 (Kaba & Joris, 2001; Srivastava & Niranjan, 2010). Prophylactic administration of ondansetron, a selective 5-HT3 receptor antagonist, is recommended for high-risk patients (Cunningham, 1998; Hayden & Cowman, 2011). Additional strategies, used alone or in combination, to reduce PONV include intraoperative use of propofol, suctioning of gastric contents, and at the end of laparoscopy as well as intraoperative administration of high inspired oxygen concentrations (≥80%), particularly during emergence (Kaba & Joris, 2001).

Continuous assessment of oxygenation, respiratory function, and cardiovascular stability is recommended until the patient regains full consciousness and demonstrates spontaneous, effective ventilation. Oxygen supplementation via nasal catheter should be provided as needed. Persistent or severe pain or respiratory compromise should prompt reassessment and may indicate underlying surgical complications (Dec & Andruszkiewicz, 2015).

2.6 INTRAOPERATIVE MONITORING

Effective intraoperative monitoring is fundamental to the success of laparoscopic procedures (Mama & de Rezende, 2015). Ensuring early detection of hemodynamic, ventilatory, and metabolic disturbances requires an integrated monitoring approach that combines standard perioperative parameters with more advanced, dynamic tools (Gerges et al., 2006).

While basic monitoring—such as electrocardiography (ECG), pulse oximetry, non-invasive blood pressure, and capnography—remains essential, the unique demands of laparoscopy often necessitate additional strategies. These may include spirometry for real-time assessment of lung mechanics, neuromuscular monitoring to guide relaxant use, and blood gas analysis to evaluate acid–base status and ventilation adequacy (Bailey et al., 2025; Dec & Andruszkiewicz, 2015; Srivastava & Niranjan, 2010).

The following subsections explore each monitoring domain in detail, focusing on its specific relevance to laparoscopic surgery and its contribution to individualized, evidence-based anesthetic management.

2.6.1 MULTIPARAMETRIC MONITORING

As previously discussed, cardiac function must be carefully monitored during laparoscopic procedures given the potential for hemodynamic fluctuations induced by increased IAP and visceral manipulation. Continuous electrocardiographic monitoring is essential for detecting alterations in heart rate (HR) and rhythm, which may arise during CO_2 insufflation or organ handling. In more complex, prolonged, or high-risk surgeries, advanced hemodynamic monitoring techniques such as pulse contour cardiac output (PiCCO) analysis or transesophageal echocardiography (TEE) may be warranted to provide a more comprehensive assessment of cardiovascular performance and guide intraoperative management (Dec & Andruszkiewicz, 2015; Gerges et al., 2006).

In addition to providing respiratory support, continuous assessment of respiratory function is essential. Carbon dioxide may be monitored in the airway using capnography or in the blood via a gas analyzer. The former has the advantage of being continuous and non-invasive (Gross et al., 2005).

In the context of pneumoperitoneum, capnography serves not only as a ventilation monitor but also as a dynamic indicator of CO_2 handling and overall patient safety. It is particularly valuable for detecting intraoperative complications such as subcutaneous emphysema, gas embolism, and capnothorax. Abrupt changes in $EtCO_2$ trends can serve as early warning signs of these events, prompting immediate intervention (Hayden & Cowman, 2011; Kaba & Joris, 2001).

End-tidal CO_2 provides a continuous, non-invasive surrogate of arterial partial pressure of carbon dioxide ($PaCO_2$); however, the gradient between these values may increase in the presence of ventilation–perfusion (V/Q) mismatch or reduced cardiac output (CO), warranting confirmation through blood gas analysis (Mama & de Rezende, 2015). In healthy, mechanically ventilated animals, $EtCO_2$ should ideally be maintained between 35 and 45 mmHg and should generally not exceed 55 mmHg (Farry, 2022a; Haskins, 2015).

Pulse oximetry is a widely used, non-invasive tool that provides continuous monitoring of peripheral oxygen saturation (SpO_2) and pulse rate. In most dogs undergoing laparoscopic procedures, particularly those breathing high FiO_2, pulse oximetry is generally sufficient for detecting clinically relevant hypoxemia, as oxygen desaturation is unlikely under these conditions (Mama & de Rezende, 2015). However, SpO_2 values can be falsely reassuring in animals under high FiO_2, as oxygen saturation may remain normal despite inadequate ventilation. Therefore, pulse oximetry should be interpreted alongside other parameters such as $EtCO_2$ and, when feasible, arterial blood gas analysis, to ensure a comprehensive evaluation of respiratory function (Haskins, 2015; Hopper, 2015; Hopper & Powell, 2013). Despite its clinical utility, pulse oximetry accuracy can be affected by several factors, including peripheral vasoconstriction, hypotension, hypothermia, motion artifacts, skin pigmentation, and electrical interference (Gross et al., 2005).

The relationship between SpO_2 and arterial partial pressure of oxygen (PaO_2) follows a sigmoidal pattern, as described by the oxygen–hemoglobin dissociation curve.

In the steep portion of this curve, small changes in SpO_2 reflect large shifts in PaO_2, making this region clinically significant for identifying the transition from normoxemia to hypoxemia. Notably, severe hypoxemia can exist even when hemoglobin is still 90% saturated (Haskins, 2015).

Blood pressure monitoring, particularly MAP, is essential to detect hemodynamic instability related to increased IAP. Mean arterial pressure should be maintained above 60 mmHg to ensure adequate tissue perfusion. Oscillometric devices are commonly used, but invasive arterial catheterization may be warranted in unstable or high-risk cases (Dec & Andruszkiewicz, 2015; Gerges et al., 2006).

Hypothermia is a frequent complication in laparoscopic surgery due to insufflation with cold CO_2. Therefore, core temperature should be monitored throughout anesthesia, and active warming measures should be employed early to maintain normothermia and prevent related complications (Gross et al., 2005; Mama & de Rezende, 2015).

When neuromuscular blockers are used during laparoscopy, objective monitoring with train-of-four (TOF) stimulation is recommended, especially during induction and recovery. A TOF count of 1–3 indicates an appropriate degree of relaxation for insufflation, while a TOF ratio ≥90% is required before extubation (Bailey et al., 2025; Srivastava & Niranjan, 2010).

Urine output may also be monitored via catheterization, particularly in pelvic procedures or unstable patients, as it serves as an indirect yet sensitive indicator of renal perfusion and hemodynamic adequacy (Dec & Andruszkiewicz, 2015).

2.6.2 SPIROMETRY AS AN ADVANCED MONITORING TOOL

Spirometry enables continuous assessment of respiratory mechanics by integrating airway pressure, flow, and volume measurements, providing real-time insight into the interaction between the ventilator and the patient's respiratory system (Calice & Moens, 2016; Moens, 2010; Xu et al., 2025). From these signals, dynamic indices such as respiratory system compliance (Crs) and airway resistance (Raw) can be derived, allowing early detection of changes in lung mechanics during anesthesia (Calice & Moens, 2016; Rozanski & Hoffman, 2004). The main spirometry-derived ventilatory parameters, their units, and clinical relevance are summarised in Table 6 (Bardoczky et al., 1993; Barreiro & Perillo, 2004; Calice & Moens, 2016; Corona & Aumann, 2011; Rozanski & Hoffman, 2004).

The current clinical use of spirometry in veterinary anesthesia and critical care has been detailed in a recent survey by Raillard et al. (2022), which reported that spirometry is more frequently applied during mechanical ventilation than during spontaneous breathing in small animals (Raillard et al., 2022).

Table 6. Spirometry-derived ventilatory parameters, units, and clinical relevance. Adapted from Rozanski et al. (2004), Barreiro and Perillo (2004), Calice and Moens (2016), Corona and Aumann (2011), and Bardoczky et al. (1993).

Parameters	Unit	Descriptions
Tidal Volume (VT)	$mL{\cdot}kg^{-1}$ (or mL)	Volume of air delivered to the lungs with each breath during mechanical ventilation. In small animals, typically 8–12 $mL{\cdot}kg^{-1}$.
Minute ventilation (Vm)	$mL{\cdot}kg^{-1}{\cdot}min^{-1}$ or $L{\cdot}min^{-1}$	Total volume of air inspired or expired per minute, calculated as VT × respiratory rate.
Peak Inspiratory Pressure (PIP)	cmH_2O	Maximum airway pressure at the end of inspiration; indicates the pressure required to overcome airway resistance and alveolar distension.
Plateau Pressure (PPlat)	cmH_2O	Pressure measured during an inspiratory pause, reflecting alveolar pressure at the end of inspiration.
Positive End-Expiratory Pressure (PEEP)	cmH_2O	Pressure maintained at the end of expiration. - PEEPE: Set by the ventilator. - PEEPI (auto-PEEP): Occurs unintentionally due to air trapping, often associated with short expiratory times or airway resistance.
Compliance of the Respiratory System (Crs)	mL/cmH_2O	A measure of lung expandability. Pneumoperitoneum or stiff lungs reduce compliance.
Airway Resistance (Raw)	$cmH_2O{\cdot}L^{-1}{\cdot}s$	Indicates resistance to airflow; affected by factors such as tube diameter, bronchospasm, or secretions.

In practice, a spirometer may be connected to an endotracheal tube in an intubated patient—either breathing spontaneously or under IPPV—or can be applied using an airtight face mask in awake animals (Moens, 2010).

Clinically, spirometry is frequently used in intensive care units to assess ventilated patients and animals with suspected hypoventilation (Calice & Moens, 2016; Rozanski & Hoffman, 2004). It also plays a role in evaluating patients with neuromuscular disorders (DeVanna et al., 2014), during weaning from neuromuscular blocking agents, and in the post-anesthetic period (Bradbrook et al., 2013).

In human medicine, spirometry is considered the standard diagnostic method for obstructive respiratory diseases, and its utility is being increasingly recognized in veterinary medicine. It can aid in the diagnosis of laryngeal paralysis, tracheal collapse (Pardali et al., 2010), bronchomalacia (Lin et al., 2023), and brachycephalic airway syndrome (Balakrishnan & Tong, 2020; Benavides et al., 2019). It can also support ventilation strategies that reduce the risk of barotrauma by tailoring parameters to individual patient physiology (Holbon, 2023). Importantly, there are no specific contraindications for spirometry in veterinary patients (Rozanski & Hoffman, 2004).

There are two main formats for the presentation of spirometric data: numerical output and graphical representation. The numerical output includes objective values that allow for precise intraoperative monitoring. Loop graphs offer a dynamic, real-time assessment of the integrity and morphology of the respiratory cycle. They illustrate the relationship between two variables—most commonly pressure–volume (PV) or flow–volume (FV)—independently of time, enabling rapid identification of mechanical abnormalities (Calice & Moens, 2016; Moens, 2010).

Adjustments in ventilator settings based on interpretation of these waveforms can assist in optimizing ventilation and improving patient safety. Deviations in waveform morphology may indicate circuit leaks, kinked tubes, overdistension, or airway obstructions, enabling prompt clinical intervention (Figure 8) (Corona & Aumann, 2011; Mellema, 2015).

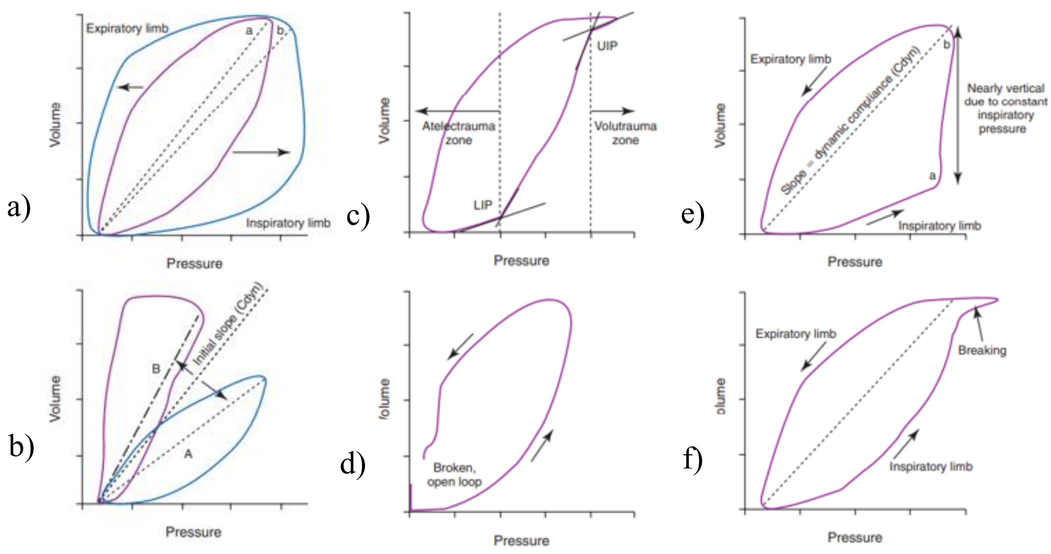

Figure 8. Representative pressure–volume (PV) loop patterns illustrating alterations in pulmonary mechanics during mechanical ventilation. Adapted from Mellema (2015).
(a, b) Changes associated with variations in compliance and airway resistance.
(c, d) Upper and lower inflection points (UIP, LIP) and circuit leaks.
(e, f) Effects of pressure-controlled ventilation and lung overdistension.

2.6.2.1 RESPIRATORY MECHANICS: COMPLIANCE AND RESISTANCE

Respiratory mechanics describe the dynamic interaction between the lungs, chest wall, and airways during ventilation, providing a functional framework for understanding ventilatory performance. Among the most clinically relevant parameters, compliance and resistance allow for the quantification of the elastic and resistive properties of the respiratory system. These two components reflect the relationship between airflow, tidal volume, and the pressure required to move air through the respiratory tract, providing critical information on ventilatory performance, especially under mechanical ventilation (Balakrishnan & Tong, 2020; Rozanski & Hoffman, 1999). These measurements are particularly relevant in laparoscopic procedures, during which alterations in IAP may significantly impact lung function (Obeid et al., 1995; Oikkonen & Tallgren, 1995; Xu et al., 2025).

Multiple morphometric and physiological variables influence respiratory mechanics. Anesthetic-induced reductions in functional residual capacity (FRC) and the loss of diaphragmatic tone contribute to decreased compliance and altered resistance. Patient-specific factors such as body condition, thoracic conformation, age, and positioning further modulate respiratory parameters (Corcoran, 1991; Hoffman, 2007;

Xu et al., 2025). For example, Bradbrook et al. (2013) demonstrated a linear correlation between body weight and respiratory system compliance (Crs) in ventilated dogs, while respiratory system resistance (Rrs) decreased proportionally with increasing weight. Such findings highlight the need for individualized ventilatory settings and underscore the clinical utility of continuous spirometric monitoring (Bradbrook et al., 2013).

2.6.2.1.1 COMPLIANCE

Respiratory system compliance refers to the ability of the lungs and chest wall to expand in response to a given pressure and is expressed in millilitres per centimetre of water $mL \cdot cmH_2O^{-1}$. It quantifies the volume change resulting from a unit change in pressure and reflects the combined elastic properties of the lungs and thoracic structures (Balakrishnan & Tong, 2020; Rozanski & Hoffman, 1999).

Clinically, compliance is divided into two subtypes: static compliance (Cstat), measured during an inspiratory pause with no airflow, and dynamic compliance (Cdyn), assessed during active ventilation and influenced by both lung elasticity and airway resistance. In anesthetized dogs, dynamic compliance can be roughly estimated using the following predictive relationship: Cdyn = body weight (kg) + 9 (Bradbrook et al., 2013).

Reduced compliance implies that higher airway pressures are required to achieve adequate tidal volume. This is commonly observed in conditions such as pulmonary edema, pneumonia, fibrosis, and contusions. In small animals, emphysema is rare; thus, most respiratory diseases are associated with decreased compliance (Rozanski & Hoffman, 1999). Additionally, factors like obesity and dorsal recumbency can impair diaphragmatic excursion and reduce compliance by altering chest wall mechanics and reducing lung volumes (Bradbrook et al., 2013).

The impact of pneumoperitoneum on respiratory system compliance has been consistently demonstrated in experimental and clinical studies. Oikkonen and Tallgren (1995) reported a 20% decrease in respiratory compliance (Crs) in dogs undergoing abdominal insufflation in dorsal recumbency, highlighting the mechanical consequences of increased intra-abdominal pressure (Oikkonen & Tallgren, 1995). In normal dogs, baseline respiratory compliance varies according to intrinsic physiological factors, including chest wall geometry. Corcoran (1991) found that narrow-chested dogs exhibited significantly lower static compliance than broad-chested individuals, and that chest wall compliance tended to decrease modestly with increasing age, underscoring the influence of morphofunctional characteristics on baseline lung mechanics (Corcoran, 1991). These observations are important when determining safe and effective ventilatory settings during laparoscopic surgery, as individual differences in baseline compliance may influence the magnitude of pneumoperitoneum-induced changes. Physiologically, total respiratory system compliance (Crs) comprises pulmonary compliance (CL) and chest wall compliance (CW), linked through the following inverse additive relationship: $1/Crs = 1/CL + 1/CW$ (Corcoran, 1991).

Due to the similar elastic properties of the lungs and chest wall, CL and CW generally contribute equally to Crs in healthy animals. However, variability introduced by body size, breed, and conformation makes the establishment of universal reference values challenging (Corcoran, 1991).

2.6.2.1.2 RESISTANCE

Respiratory resistance refers to the non-elastic opposition to airflow during inspiration and expiration. It quantifies the pressure required to generate a given flow rate through the airways and is expressed in $cmH_2O \cdot L^{-1} \cdot s^{-1}$. This parameter is particularly valuable for assessing airway patency and guiding ventilatory management in both spontaneous and mechanically ventilated patients (Balakrishnan & Tong, 2020; Rozanski & Hoffman, 1999).

Resistance includes two components: airway resistance (Raw), related to airflow through the trachea and bronchi, and tissue resistance (Rtissue), reflecting the viscoelastic properties of the lung parenchyma and thoracic tissues (Hoffman, 2007). Among these, Raw is the most clinically relevant, as it is sensitive to variations in airway geometry, endotracheal tube diameter, and breathing circuit configuration. Bradbrook et al. (2013) proposed a simplified predictive equation to estimate respiratory system resistance (Rrs) in dogs: $Rrs = [\text{body weight (kg)} \times -0.1] + 7$ (Bradbrook et al., 2013)

This inverse relationship between resistance and body size suggests that smaller patients, with narrower airways and reduced lung volumes, are more prone to elevated resistance values (Bradbrook et al., 2013).

Physiological resistance is typically low in healthy lungs, allowing for efficient ventilation. However, pathological states such as tracheal collapse, chronic bronchitis, asthma, and brachycephalic airway syndrome markedly increase Raw and impede airflow. Clinical assessment of resistance can help identify intraoperative complications such as bronchospasm, secretion accumulation, or circuit obstruction (Balakrishnan & Tong, 2020).

2.6.2.2 SPIROMETRY IN PNEUMOPERITONEUM

Respiratory mechanics are highly sensitive to changes in IAP, making spirometry a particularly valuable monitoring tool during PNP (Bardoczky et al., 1993; Xu et al., 2025).

In a human clinical study, Bardoczky et al. (1993) demonstrated that peak and plateau airway pressures increased by 50% and 81%, respectively, while compliance decreased by 47% during pneumoperitoneum. Notably, even after deflation, peak and plateau pressures remained elevated, and compliance recovered only to 86% of baseline values. These findings confirm that the mechanical consequences of IAP persist beyond desufflation and must be actively managed throughout the perioperative period (Bardoczky et al., 1993).

In veterinary anesthesia, Calice (2016) reported a case series illustrating the practical benefits of modern spirometry in identifying intraoperative complications. The recognition and interpretation of pressure–volume (PV) and flow–volume (FV) loops allowed for early diagnosis of iatrogenic pneumothorax, ventilator-patient dyssynchrony, partial airway obstruction, and circuit leaks. In two laparoscopic cases, a marked reduction in dynamic compliance was detected before any significant alteration in $EtCO_2$ or SpO_2 occurred, enabling timely corrective action (Calice & Moens, 2016).

Another advantage highlighted by Calice (2016) is the availability of real-time loop displays, particularly PV loops, which are standard in many advanced anesthesia machines. These can be saved and compared during the procedure, allowing for the detection of progressive deterioration in lung mechanics over time. Unlike traditional monitors, spirometry offers earlier detection of subtle mechanical changes, reinforcing its role in preemptive ventilatory management (Calice & Moens, 2016).

Koivusalo and Lindgren (2000) further emphasized the utility of side-stream spirometry in laparoscopic settings, reporting that a drop in compliance and simultaneous rise in airway pressures reliably signaled the onset of pneumothorax before clinical signs or capnographic abnormalities were present (Koivusalo & Lindgren, 2000).

2.6.3 BLOOD GAS ASSESSMENT IN THE CONTEXT OF PNEUMOPERITONEUM

Blood gas analysis is a critical tool for assessing the physiological impact of laparoscopic procedures, particularly in the presence of CO_2-induced pneumoperitoneum. The increase in IAP during laparoscopy compromises pulmonary function and can lead to hypercapnia, respiratory acidosis, or mixed acid–base disturbances (Hopper, 2015; McMahon et al., 1993).

Even under controlled mechanical ventilation, elevations in $PaCO_2$ and reductions in blood pH may occur, especially at IAPs of 8–10 mmHg, which are commonly regarded as moderate but are not physiologically neutral. These effects can persist into the postoperative period and are not solely attributable to anesthetic agentes (Koivusalo & Lindgren, 2000).

While general anesthesia contributes to ventilatory depression, the additional physiological burden of PNP significantly exacerbates the risk of gas exchange impairment. This underscores the importance of real-time hemogasometric monitoring to detect and promptly address acid–base imbalances (Crystal, 2015; Ferreira et al., 2002).

Arterial blood gas (ABG) analysis is considered the gold standard for evaluating ventilation, oxygenation, and acid–base status. However, its invasive nature limits its routine use in small animal anesthesia. In clinically stable patients, peripheral venous blood gas (VBG) sampling offers a practical alternative. Although less informative for oxygenation, VBG provides clinically reliable estimates of pH, partial pressure of carbon dioxide (pCO_2), and bicarbonate in cardiovascularly and hemodynamically stable patients, particularly when trends over time are evaluated rather than absolute values (Brandenburg & Dire, 1998; Ilkiw et al., 1991). Reference values for arterial and venous blood gas parameters in healthy dogs are summarized in Table 7, providing a comparative baseline for the interpretation of intraoperative and postoperative findings (Silverstein & Hopper, 2015).

Table 7. Comparative blood gas values in healthy dogs from different sampling sites. pCO_2 and pO_2 are reported in kPa (converted from mmHg). Adapted from Silverstein and Hopper (2015).

	Arterial	**Mixed Venous**	**Jugular Venous**	**Cephalic Vein**
pH	7.40 ± 0.03	7.36 ± 0.02	7.35 ± 0.02	7.36 ± 0.02
PCO_2 (kPa)	4.93 ± 0.40	5.73 ± 0.53	5.60 ± 0.67	5.73 ± 0.40
Base deficit ($mmol{\cdot}L^{-1}$)	-2 ± 2	-1 ± 1	-2 ± 2	-1 ± 1
Bicarbonate mmol/L	21 ± 2	23 ± 2	22 ± 2	23 ± 1
Total CO_2 ($mmol{\cdot}L^{-1}$)	22 ± 2	24 ± 2	23 ± 2	24 ± 2
PO_2 (kPa)	13.60 ± 0.93	7.07 ± 1.33	7.33 ± 1.33	7.73 ± 1.20

2.6.3.1 POINT-OF-CARE BLOOD GAS ANALYSIS

Point-of-care (POC) systems have gained popularity in veterinary anesthesia due to their accessibility, rapid analysis time, and minimal blood volume requirements. Devices like the i-STAT® analyzer allow real-time assessment of key parameters, including pH, pCO_2, HCO_3^-, base excess, and lactate, using approximately 100 µL of blood (Harter et al., 2014; Steinfelder-Visscher et al., 2008; Verwaerde et al., 2002).

Validated for veterinary use, the i-STAT provides results comparable to standard benchtop analyzers, particularly for acid–base and respiratory variables (Bingham et al., 1999; Larcher et al., 2023). During laparoscopic procedures, its portability and fast feedback enable timely interventions when shifts in ventilation or perfusion compromise homeostasis (Ferreira et al., 2002; Harter et al., 2014).

2.6.3.2 SAMPLE COLLECTION AND HANDLING

Accurate blood gas interpretation relies on appropriate collection and handling. Preanalytical errors such as air contamination, excess anticoagulant, or delayed analysis can skew results and impact clinical decisions (Faria et al., 2024; Hopper, 2015).

Heparinized syringes—preferably with lyophilized or dry-balanced heparin—should be used to minimize clotting and dilutional artifacts. Samples must be collected anaerobically, and if analysis is delayed beyond 10–15 minutes, they should be stored in ice to reduce ongoing cellular metabolism (Faria et al., 2024; Hopper, 2015).

Site selection also influences results. Jugular venous blood is more consistent with arterial values than cephalic samples and is thus preferred for VBG in perioperative settings (Ilkiw et al., 1991; Larcher et al., 2023). For repeated measurements or concurrent invasive pressure monitoring, arterial catheterization (e.g., dorsal metatarsal artery) is ideal (Welsh, 2009).

2.6.3.3 INTERPRETATION OF KEY BLOOD GAS PARAMETERS

During pneumoperitoneum, rapid and dynamic shifts in acid–base status necessitate careful interpretation of blood gas parameters. Compensatory mechanisms, while present, are typically insufficient to restore full homeostasis during acute changes (Hopper, 2015).

Key parameters to monitor include:

- **Partial pressure of carbon dioxide** (pCO_2): An increase indicates impaired CO_2 elimination due to reduced alveolar ventilation and diaphragmatic excursion, leading to respiratory acidosis (Crystal, 2015; Hopper, 2015).
- **Bicarbonate** (HCO_3^-): This buffer increases slowly through renal compensation in response to respiratory acidosis, but such compensation is often incomplete during the short duration of laparoscopic procedures (Hopper, 2015).
- **Base Excess** (BE): Reflects the metabolic contribution to acid–base balance. Unlike HCO_3^-, BE is not directly influenced by pCO_2 and thus offers a more isolated view of metabolic disturbances (Hopper, 2015).

- **Lactate** (Lac): Elevations may indicate tissue hypoperfusion, reduced venous return, or oxygenation deficits associated with pneumoperitoneum. Serial measurements help identify early metabolic compromisse (Acierno & Mitchell, 2007; Hughes et al., 1999).

2.7 THE CRITICAL ROLE OF THE VETERINARY NURSE IN LAPAROSCOPIC ANAESTHESIA AND SURGICAL SAFETY

As laparoscopic techniques become increasingly prevalent in veterinary practice, the physiological implications of pneumoperitoneum, mechanical ventilation, and patient positioning must not be underestimated. Although these procedures, are minimally invasive from a surgical perspective, they can induce significant cardiovascular and respiratory changes, demanding a level of perioperative vigilance that goes far beyond basic patient care. In this context, the veterinary nurse assumes a central and indispensable role (Farry, 2022; Freeman, 2003).

Throughout the anesthetic continuum—from admission to postoperative recovery—veterinary nurses contribute actively to the planning, execution, and safety of each procedure. Their responsibilities include patient assessment, equipment preparation, administration of pre-anesthetic medications, and the accurate interpretation of physiological data from multiparametric monitors (Clancy, 2023a). In laparoscopic procedures, anticipating the effects of increased IAP is essential to ensure timely intervention and prevent complications (Bardoczky et al., 1993; Calice & Moens, 2016). Additionaly, veterinary nurses play a crucial role in ventilatory management, including the adjustment of ventilator settings—such as tidal volume, respiratory rate, and positive end-expiratory pressure (PEEP)—in response to changes in lung compliance and capnographic trends associated with pneumoperitoneum.

Interpreting changes in spirometry, capnography, or neuromuscular blockade requires not only technical competence but also the ability to recognize deviations from expected patterns and communicate these effectively to the attending anesthetist or surgeon. This real-time surveillance is vital, particularly when subtle trends precede critical events such as hypoventilation, barotrauma, or cardiovascular depression (Asorey et al., 2020; Bailey et al., 2025; Raillard et al., 2022). The ability to recognize and manage intraoperative complications and emergency situations, ensuring a rapid and effective response to critical events, is a highly valuable competency of the veterinary nurse.

Moreover, the variability among small animal patients—particularly in terms of size, thoracic morphology, and baseline respiratory function—requires nurses to tailor their monitoring strategy accordingly (Farry, 2022b; Freeman, 2003).

Beyond the intraoperative period, veterinary nurses play a key role in ensuring smooth recovery, including thermoregulation, management of neuromuscular blockade reversal, and postoperative monitoring of ventilation and acid–base status—often using peripheral venous blood gas analysis where arterial access is impractical (Brandenburg & Dire, 1998; Ferreira et al., 2002). Their documentation and clinical observations contribute to case auditing and support the continuous refinement of anesthetic and surgical protocols (Clancy, 2023).

Importantly, the veterinary nurse also serves as the client's first point of contact. Their ability to explain the procedure, associated risks, and monitoring plan in a clear and compassionate manner strengthens the client–clinic relationship. This is particularly relevant in elective procedures, where the completion of anesthetic consent forms represents not only a legal requirement but also an opportunity to demonstrate professionalism and empathy (Clancy, 2023b; Farry, 2022b; Freeman, 2003).

The success of laparoscopic anesthesia does not rely solely on individual competence but on effective teamwork. The entire surgical team must be familiar with the planned procedure, the expected physiological effects of pneumoperitoneum, and the potential intraoperative or postoperative complications. Effective communication—particularly between the nurse, anesthetist, and surgeon—is fundamental to optimizing outcomes and reducing the risks associated with anestesia (Farry, 2022; Freeman, 2003).

Given the increasing complexity of surgical procedures and the growing reliance on advanced physiological monitoring, ongoing professional development is imperative. Certification programs in Anaesthesia and Analgesia provide advanced training in the interpretation of ventilatory loops, capnographic waveforms, and blood gas analysis (Clancy, 2023; Rozanski & Hoffman, 1999). Participation in clinical workshops, multidisciplinary rounds, and evidence-based training further enhances the nurse’s ability to contribute meaningfully to high-risk anesthesia care (Farry, 2022).

3. MATERIALS AND METHODS

This prospective experimental study was conducted at the Hospital Veterinário de São Bento between February 1 and October 1, 2025. During this period, data were collected from client-owned animals admitted for elective surgical procedures at the institution.

Data were collected using a standardized recording sheet and included age, breed, sex, body weight, body surface area (BSA), type of surgical procedure, baseline inspiratory pressure, start and end time of pneumoperitoneum, and time to end-tidal CO_2 normalization ($EtCO_2$; target range 35–45 mmHg), following desufflation. Body surface area was calculated from body weight using a standard canine formula [BSA (m^2) = 0.101 × body weight (kg)^(2/3)] (Laflamme, 1997).

All procedures were performed in accordance with current animal welfare regulations, and written informed consent was obtained from the owners prior to enrolment (Appendix I and II) for the use and statistical analysis of clinical data. The study protocol was reviewed and approved by the Master's Programme Board and the Technical-Scientific Council (CTC) of the institution.

To ensure methodological consistency, all patients were managed under a standardized perioperative protocol, including fasting, anesthetic management, patient positioning, intra-abdominal pressure (IAP), and intraoperative monitoring. All surgical procedures were performed by the same two surgeons, and data collection and monitoring were consistently supervised by the same two trained observers.

3.1 STUDY DESIGN

All animals were studied immediately after induction of anaesthesia. To minimise physiological variability, painful or noxious stimulation was avoided during data collection, thereby avoiding confounding alterations in cardiorespiratory parameters unrelated to pneumoperitoneum or patient positioning.

Pneumoperitoneum was established by carbon dioxide (CO_2) insufflation via a Veress needle, using the lowest effective flow rate, which did not exceed 2.5 $L \cdot min^{-1}$. Insufflation was initiated with the patient positioned in dorsal recumbency. Standard laparoscopic positioning was maintained throughout the procedure, with positional adjustments limited to dorsal recumbency or a controlled dorsolateral tilt of approximately 15°, according to the predefined observation periods. Ventilatory settings were kept constant during all study phases, as described previously.

The exact time of pneumoperitoneum initiation and CO_2 desufflation was recorded for each animal. Although the duration of pneumoperitoneum was not standardised, a stabilisation period of approximately 15 minutes following insufflation was defined in order to reduce the influence of transient changes on data analysis. Observation periods were defined from T0 to T5, corresponding to distinct phases of anaesthesia, pneumoperitoneum, and patient positioning (Table 8).

Table 8. Experimental design and variables assessed at predefined timepoints.

Timepoint	Patient position	IAP (mmHg)	Variables assessed
T0	Dorsal recumbency	0	Spirometry (VT, Vm, Cdyn, Rrs); $EtCO_2$; haemodynamics (HR, MAP, SpO_2, temperature); venous blood gas analysis (pH, pCO_2, HCO_3^-, BE, lactate)
T1 *(5 min after insufflation)*	Dorsal recumbency	10	Spirometry; $EtCO_2$; haemodynamics
T2 *(prior to repositioning)*	Dorsal recumbency	10	Spirometry; $EtCO_2$; haemodynamics
T3 *(after repositioning)*	Dorsolateral tilt (15°)	10	Spirometry; $EtCO_2$; haemodynamics
T4 *(pre-desufflation)*	Dorsolateral tilt (15°)	10	Spirometry; $EtCO_2$; haemodynamics; venous blood gas analysis
T5 *(5 min after desufflation)*	Dorsal recumbency	0	Spirometry; $EtCO_2$; haemodynamics

Note: VT = tidal volume; Vm = minute ventilation; Cdyn = dynamic compliance; Rrs = airway resistance; $EtCO_2$ = end-tidal carbon dioxide; HR = heart rate; MAP = mean arterial pressure; SpO_2 = peripheral oxygen saturation; BE = base excess.

Respiratory, haemodynamic, and temperature variables were recorded at each timepoint. Venous blood gas analysis (pH, pCO_2, bicarbonate, base excess, and lactate) was performed at baseline (T0) and at the end of pneumoperitoneum (T4). For this purpose, 1 mL of jugular venous blood was collected anaerobically by direct venipuncture into heparinised syringes, with minimal restraint. Samples were analysed immediately using a point-of-care blood gas analyser (i-STAT®, Abbott) with CG4+

cartridges. Values of pH and pCO_2 were automatically temperature-corrected by the device.

Following completion of all study-related measurements (T5), animals remained mechanically ventilated with an inspired oxygen fraction (FiO_2) of 80% until recovery from anaesthesia. The time elapsed until normalisation of end-tidal carbon dioxide ($EtCO_2$) after CO_2 desufflation was recorded for each patient.

3.1.1 EXCLUSION CRITERIA

During the recruitment phase, four Dachshund dogs were initially enrolled but subsequently excluded due to poor tolerance of pneumoperitoneum at an intra-abdominal pressure of 10 mmHg. These animals developed early ventilatory compromise following CO_2 insufflation, requiring immediate reduction of intra-abdominal pressure and precluding continuation of the experimental protocol.

In addition, two mixed-breed dogs were excluded due to marked thoracic deformities likely to significantly alter baseline respiratory mechanics and confound the interpretation of ventilatory changes associated with pneumoperitoneum and thoracic conformation. All exclusions were applied to prioritise patient safety and preserve methodological integrity.

3.2 ANIMALS

A total of sixty-four healthy dogs of various breeds were enrolled, with a mean age of 1.93 ± 1.66 years (range: 0.5 years [6 months] to 9 years). All animals were client-owned and underwent routine diagnostic or therapeutic laparoscopic procedures, including elective ovariectomy, cryptorchid castration, and cystotomy.

Only dogs classified as American Society of Anesthesiologists (ASA) physical status I, with predefined thoracic conformation and no structural abnormalities detected on clinical or imaging evaluation, were included. All animals underwent a complete pre-anesthetic clinical examination with particular emphasis on the respiratory system, supported by thoracic radiography and complemented by routine laboratory testing.

Exclusion criteria comprised failure to meet inclusion requirements, evidence of increased clinical risk or discomfort during the procedure, aggressive or aberrant behaviour, or clinical or laboratory findings incompatible with anesthetic safety. Dogs that developed intraoperative complications preventing completion of the experimental protocol were also excluded.

Animals were allocated into three groups according to thoracic conformation: deep-chested, intermediate, and broad-chested. All dogs were fasted for 8-12 hours from solid food and 2 hours from water prior to anesthesia, in accordance with established veterinary anesthetic guidelines (Gross et al., 2005).

3.2.1 ESTIMATION OF THORACIC CONFORMATIONS

Thoracic conformation was classified in all dogs by calculating the thoracic depth-to-width (D:W) ratio. Thoracic depth was measured on right lateral thoracic radiographs as the distance from the cranial margin of the xiphoid process to the ventral border of the vertebral column, along a line perpendicular to the vertebral axis. Thoracic width was measured on ventrodorsal radiographs as the distance between the medial borders of the eighth ribs at their points of maximum lateral curvature. Based on these measurements, dogs were categorised into three groups: deep-chested (shape 3) (D:W ratio ≥ 1.25; n = 2), broad-chested (shape 1) (D:W ratio ≤ 0.75; n = 10), and intermediate (shape 2) ($0.75 < D:W < 1.25$; n = 52).

3.3 ANAESTHESIA

A standardized anaesthetic protocol was applied in all cases and conducted by the same anaesthetist to minimize inter-operator variability. Pre-anaesthetic medication consisted of dexmedetomidine (Sedadex® 0.5 $mg \cdot mL^{-1}$, Dechra) administered intramuscularly at 0.0025 $mg \cdot kg^{-1}$ and methadone (Semfortan® 10 $mg \cdot mL^{-1}$, Dechra) at 0.3 $mg \cdot kg^{-1}$. Twenty minutes later, an intravenous catheter was placed in a peripheral vein, and maropitant (Vetemex® 10 $mg \cdot mL^{-1}$, Virbac) was administered intravenously at 1 $mg \cdot kg^{-1}$ as part of a multimodal pre-emptive analgesic and antiemetic protocol. Preoxygenation with 100% oxygen via facemask was performed for 3–5 minutes in a pre-surgical preparation area.

Anaesthesia was induced with intravenous propofol (Propofol Lipuro® 10 mg·mL^{-1}, B. Braun), titrated to effect until endotracheal intubation was achieved. The trachea was intubated using a high-volume, low-pressure (HVLP) cuffed polyvinyl chloride (PVC) endotracheal tube, selecting the largest diameter that could be advanced without resistance. Endotracheal tube length was measured from the incisors to the thoracic inlet (level of the shoulder), and cuff inflation pressure was standardized at 20 cmH_2O using a calibrated manometer.

Anaesthesia was maintained with isoflurane (Vetflurane® 1000 mg·mL^{-1}, Virbac) vaporized in oxygen, the endotracheal tube was connected to a circle breathing system. Following transfer to the operating room, the system was connected to the anaesthetic workstation, which underwent a standardized leak test each morning prior to clinical use. At this stage, the inspired oxygen fraction (FiO_2) was reduced from 100% to 40% by blending oxygen with medical air.

Neuromuscular blockade was achieved using atracurium besylate (Atracurium® 10 mg·mL^{-1}, Basi) administered intravenously at an initial dose of 0.1 mg·kg^{-1}, injected slowly. Supplemental doses of 0.05 mg·kg^{-1} IV were administered whenever the train-of-four (TOF) ratio exceeded 75%.

Mechanical ventilation was provided using a GE Aisys® anaesthesia workstation in pressure-controlled ventilation (PCV) mode. Inspiratory pressure was initially adjusted to achieve an end-tidal carbon dioxide ($EtCO_2$) within the target range of 35–45 mmHg and was thereafter kept constant throughout the procedure. All other ventilatory parameters were also maintained unchanged, including a respiratory rate of 10 breaths·min^{-1}, an inspiratory-to-expiratory ratio of 1:2, and a positive end-expiratory pressure (PEEP) of 4 cmH_2O.

Intraoperative fluid therapy consisted of Ringer's lactate solution (B. Braun), administered intravenously at a rate of 5 mL·kg^{-1}·h^{-1} using a calibrated infusion pump (Enmind® Veterinary Pump EN-V5).

3.4 MONITORING

Intraoperative monitoring was performed using a multiparameter anaesthetic workstation (GE Aisys®), a train-of-four (TOF) neuromuscular monitor (TOF-Watch SX®), and a point-of-care blood gas analyser (i-STAT Alinity V®, Abaxis). Spirometry constituted the primary advanced respiratory monitoring tool in this study. Continuous monitoring included electrocardiography (ECG), oscillometric non-invasive blood pressure (NIBP), pulse oximetry, capnography, spirometric measurements, oesophageal temperature monitoring, and neuromuscular blockade assessment using TOF. Depth of anaesthesia was additionally evaluated using clinical indicators, including palpebral reflex and eye position, while intermittent blood gas analysis was performed to assess acid–base and metabolic status.

The following variables were recorded for the purposes of the study:

- **Respiratory variables:** tidal volume (VT, mL), end-tidal carbon dioxide ($EtCO_2$, mmHg), dynamic compliance (Cdyn, $mL \cdot cmH_2O^{-1} \cdot kg^{-1}$), airway resistance (Rrs, $cmH_2O \cdot L^{-1} \cdot s^{-1}$) and minute ventilation (Vm).
- **Haemodynamic variables:** heart rate (HR, $beats \cdot min^{-1}$), mean arterial pressure (MAP, mmHg), peripheral oxygen saturation (SpO_2, %), and body temperature (°C).
- **Blood gas and metabolic variables:** pH, partial pressure of carbon dioxide (pCO_2, kPa), bicarbonate (HCO_3^-, $mmol \cdot L^{-1}$), base excess (BE, $mmol \cdot L^{-1}$), and lactate ($mmol \cdot L^{-1}$).

Spirometric monitoring was performed using side-stream flow sensors (D-lite™ for endotracheal tubes ≥ 6 mm; Pedi-lite™ for endotracheal tubes < 6 mm), positioned between the endotracheal tube (ETT) and the Y-piece of the breathing circuit. This system provided continuous, breath-by-breath measurements of tidal volume, respiratory flow, and airway pressures, as well as derived indices of respiratory mechanics, including dynamic compliance (Cdyn) and airway resistance (Rrs). Graphical displays, including pressure–volume (PV) and flow–volume (FV) loops, were continuously assessed to detect changes in pulmonary mechanics throughout the procedure.

At the end of the surgical procedure, neuromuscular recovery was evaluated using TOF monitoring. Tracheal extubation was performed only after confirmation of a

TOF ratio ≥ 90%, together with the return of spontaneous ventilation and protective airway reflexes. Animals were subsequently transferred to the recovery area, where postoperative monitoring was continued, and supplemental oxygen was administered via facemask as required.

3.5 STATISTICAL ANALYSES

Continuous variables were screened for outliers and summarised as mean ± standard deviation (SD) for normally distributed data or median and interquartile range (IQR) otherwise, while categorical variables were expressed as frequencies and percentages. Normality was assessed using the Shapiro–Wilk test and homogeneity of variances using Levene's test.

Between-group comparisons were performed using one-way ANOVA with Tukey's post hoc test for normally distributed variables with homogeneous variances, or the Kruskal–Wallis test with Dunn–Bonferroni post hoc comparisons when parametric assumptions were not met.

Cumulative changes between baseline and pre-desufflation (ΔT4–T0) and between baseline and post-desufflation (ΔT5–T0) were calculated for ventilatory, haemodynamic, and blood gas variables. Δ values were compared among thoracic conformation groups using one-way ANOVA with Tukey's post hoc test or the Kruskal–Wallis test with Dunn–Bonferroni post hoc comparisons, according to data distribution. Within-subject comparisons between baseline (T0) and post-desufflation (T5) were performed using paired t-tests or Wilcoxon signed-rank tests, as appropriate.

Longitudinal analyses of ventilatory parameters were performed using linear mixed-effects models including Time, Thoracic Conformation, and their interaction as fixed effects, with dog ID as a random intercept to account for repeated measurements. Models were fitted using restricted maximum likelihood with Satterthwaite-adjusted degrees of freedom.

Correlation analyses were performed using Pearson's or Spearman's correlation coefficients, according to data distribution. Associations were explored between cumulative venous and capnographic carbon dioxide changes (ΔpCO_2 vs $\Delta EtCO_2$), changes in dynamic compliance and airway resistance (ΔCdyn vs ΔRrs), and between body weight and baseline tidal volume normalised to body mass (VT_0, $mL \cdot kg^{-1}$).

End-tidal CO_2 normalisation time after desufflation was compared among thoracic conformation groups using the Kruskal–Wallis test followed by Dunn–Bonferroni post hoc comparisons.

All statistical analyses were performed using Jamovi (version 2.7.13; The jamovi Project, 2024, Sydney, Australia).

For all analyses, statistical significance was set at $p < 0.05$.

4. RESULTS

4.1 DESCRIPTIVE STATISTICS

A total of 64 ASA I dogs were enrolled in the study, the majority of which underwent elective laparoscopic ovariectomy (90.6%), with a smaller proportion undergoing cryptorchidectomy (6.3%) or laparoscopic-assisted cystotomy (3.1%). Consequently, the study population consisted predominantly of female dogs (95.3%).

Age ranged from 0.5 to 9 years (mean 1.93 ± 1.66 years), and body weight ranged from 2.7 to 49.5 kg (mean 15.18 ± 11.30 kg), reflecting a heterogeneous distribution across body size categories (small 48.4%, medium 28.1%, and large 23.4%).

Thoracic morphometric analysis demonstrated a wide distribution of thoracic indices (0.60–1.93). Most dogs were classified as having an intermediate thoracic conformation (chest shape 2; $n = 52$), while broad-chested (shape 1; $n = 10$) and deep-chested dogs (shape 3; $n = 2$) were less represented.

All dogs were ventilated using pressure-controlled ventilation. Baseline inspiratory pressure averaged 8.55 ± 0.96 cmH_2O. The duration of pneumoperitoneum was 29.27 ± 10.78 minutes (range 14–71 minutes).

The time required for end-tidal CO_2 normalisation following desufflation showed marked interindividual variability (mean 11.05 ± 9.69 minutes; range 1–50 minutes), indicating heterogeneous CO_2 elimination dynamics within the study population.

Descriptive statistics for demographic, morphometric, and baseline ventilatory variables are summarized in table 9.

Table 9. Descriptive statistics of demographic and baseline continuous variables.

Variable	Mean ± SD	Median	Range
Age (years)	1.93 ± 1.66	1.20	0.5–9.0
Weight (kg)	15.18 ± 11.30	11.03	2.7–49.5
Thoracic index	0.893 ± 0.180	0.860	0.60–1.93
BSA (m^2)	0.597 ± 0.307	0.51	0.20–1.41
Duration of pneumoperitoneum (min)	29.27 ± 10.78	26	14–71
Baseline inspiratory pressure (cmH_2O)	8.55 ± 0.96	8	7–11
$EtCO_2$ normalisation time (min)	11.05 ± 9.69	9	1–50

Note: BSA = body surface area; $EtCO_2$ = end-tidal carbon dioxide.

4.2 BASELINE COMPARABILITY BETWEEN THORACIC CONFORMATION GROUPS

Age did not differ significantly between thoracic conformation groups (Kruskal–Wallis $\chi^2 = 0.155$, $p = 0.926$). Similarly, no significant differences were observed for body weight ($\chi^2 = 3.66$, $p = 0.160$) or body surface area (BSA; $\chi^2 = 3.79$, $p = 0.150$), with no statistically significant pairwise comparisons identified.

Baseline haemodynamic variables (heart rate, mean arterial pressure, peripheral oxygen saturation, and body temperature) and venous blood gas parameters (pH, pCO_2, bicarbonate, base excess, and lactate) were comparable across thoracic conformation groups at baseline (T0), with no statistically significant differences observed (*all* $p > 0.05$), although baseline $EtCO_2$ approached the threshold for statistical significance.

In contrast, baseline ventilatory parameters related to respiratory mechanics differed significantly between groups, with both tidal volume and dynamic compliance showing significant between-group differences ($p < 0.05$).

Baseline demographic, morphometric, physiological, and blood gas variables across thoracic conformation groups are summarised in Table 10.

Table 10. Baseline comparability between thoracic conformation groups.

Variable	Broad-chested (n = 10) Mean ± SD	Intermediate (n = 52) Mean ± SD	Deep-chested (n = 2) Mean ± SD	p-value
Demographic and morphometric variables				
Age (years)	2.30 ± 2.58	1.86 ± 1.47	1.95 ± 1.34	0.926
Body weight (kg)	10.8 ± 6.72	15.5 ± 11.8	27.3 ± 1.77	0.160
BSA (m^2)	0.489 ± 0.207	0.605 ± 0.320	0.940 ± 0.042	0.150
Baseline physiological variables (T0)				
VT (mL)	154.0 ± 108.9	241.7 ± 173.9	586.5 ± 62.9	0.038
Vm ($L \cdot min^{-1}$)	1.63 ± 1.15	2.36 ± 1.77	5.80 ± 0.71	0.056
Cdyn ($mL \cdot cmH_2O^{-1}$)	18.2 ± 13.4	29.8 ± 20.5	65.5 ± 19.1	0.043
Rrs ($cmH_2O \cdot L^{-1} \cdot s^{-1}$)	11.7 ± 7.20	9.54 ± 6.58	2.50 ± 0.71	0.110
SpO_2 (%)	99.2 ± 1.48	99.3 ± 1.15	98.5 ± 2.12	0.753
$EtCO_2$ (mmHg)	39.2 ± 3.49	36.7 ± 2.92	35.5 ± 0.71	0.050
HR (bpm)	89.7 ± 15.6	87.3 ± 20.0	99.0 ± 55.2	0.965
MAP (mmHg)	79.2 ± 18.4	74.6 ± 14.4	73.0 ± 7.1	0.816
Temperature (°C)	36.84 ± 0.77	36.58 ± 0.86	36.75 ± 1.77	0.607
pH	7.258 ± 0.036	7.273 ± 0.032	7.228 ± 0.048	0.172
pCO_2 (kPa)	6.31 ± 0.72	5.93 ± 0.67	6.45 ± 0.29	0.140
HCO_3^- ($mmol \cdot L^{-1}$)	21.13 ± 1.86	20.48 ± 1.66	20.15 ± 1.34	0.589
Lactate ($mmol \cdot L^{-1}$)	0.94 ± 1.00	0.79 ± 0.58	0.89 ± 0.12	0.355
BE ($mmol \cdot L^{-1}$)	−6.10 ± 2.03	−6.42 ± 1.79	−7.50 ± 2.12	0.577

Note: Physiological and blood gas variables are reported at baseline (T0). *p*-values refer to overall between-group comparisons using Kruskal–Wallis tests. Results for the deep-chested group should be interpreted with caution due to the small sample size. VT = tidal volume; Vm = minute ventilation; Cdyn = dynamic compliance; Rrs = airway resistance; $EtCO_2$ = end-tidal carbon dioxide; HR = heart rate; MAP = mean arterial pressure; BSA = body surface area; pCO_2 = partial pressure of carbon dioxide; HCO_3^- = bicarbonate; BE = base excess.

4.3 GLOBAL CUMULATIVE VENTILATORY AND HAEMODYNAMIC EFFECTS OF PNEUMOPERITONEUM (ΔT4–T0)

Paired comparisons between baseline (T0) and the pre-desufflation time point (T4) were performed to evaluate the global cumulative effects of pneumoperitoneum on ventilatory and haemodynamic variables, independently of thoracic conformation.

Non-parametric paired analyses (Wilcoxon signed-rank test) applied to cumulative changes (ΔT4–T0) revealed significant alterations in several ventilatory variables (Figure 9). Dynamic compliance (Cdyn, $mL \cdot cmH_2O^{-1}$) was significantly reduced at T4 compared with baseline ($W = 2012$, $p < 0.001$), while airway resistance (Rrs, $cmH_2O \cdot L^{-1} \cdot s^{-1}$) increased significantly over the same interval ($W = 424$, $p = 0.001$). Tidal volume (VT, mL) also decreased significantly from baseline to T4 ($W = 2068$, $p < 0.001$), accompanied by a significant reduction in minute ventilation (Vm, $L \cdot min^{-1}$) ($W = 1825$, $p < 0.001$). A small but statistically significant change in peripheral oxygen saturation (SpO_2, %) was observed between T0 and T4 ($W = 454$, $p = 0.020$).

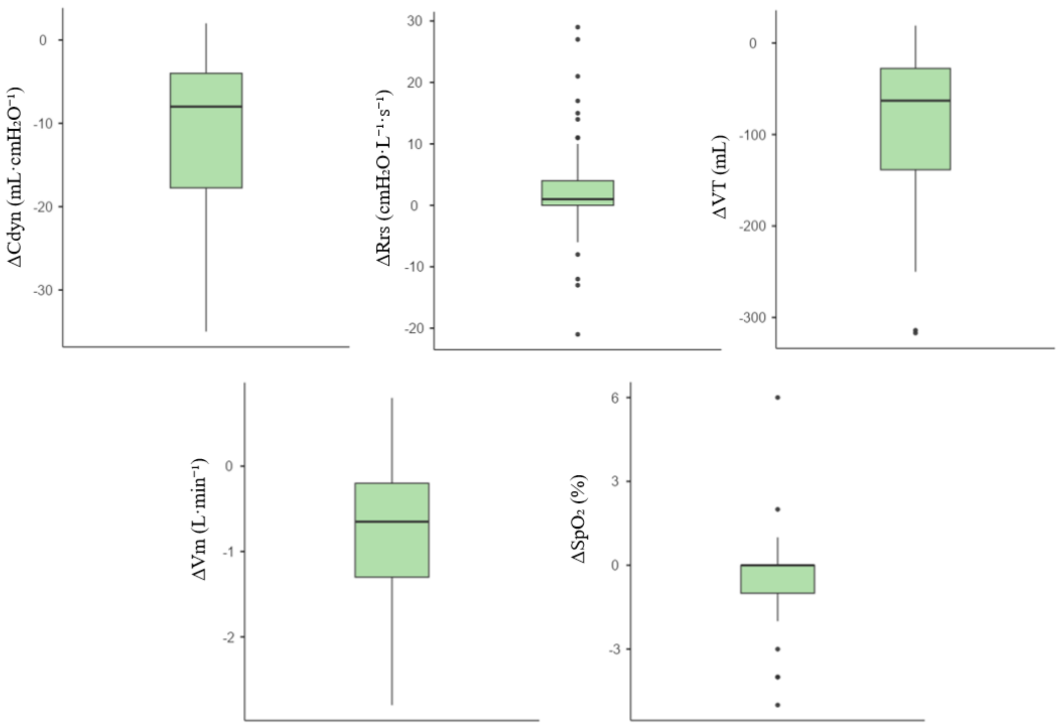

Figure 9. Cumulative changes in ventilatory mechanics induced by pneumoperitoneum, expressed as individual differences between baseline and pre-desufflation (ΔT4–T0). Variables shown include dynamic compliance (ΔCdyn), airway resistance (ΔRrs), tidal volume (ΔVT), minute ventilation (ΔVm), and peripheral oxygen saturation (ΔSpO_2).

Paired comparisons between baseline (T0) and (T4) were performed using paired t-tests for normally distributed variables (Figure 10). End-tidal carbon dioxide ($EtCO_2$, mmHg) increased significantly from baseline to T4 ($t(63) = -24.69$, $p < 0.001$). Mean arterial pressure (MAP, mmHg) also increased significantly over the same interval ($t(63) = -7.58$, $p < 0.001$), whereas heart rate (HR, bpm) did not differ significantly between time points ($t(63) = 1.54$, $p = 0.128$). Body temperature (°C) decreased significantly from T0 to T4 ($t(63) = 8.69$, $p < 0.001$).

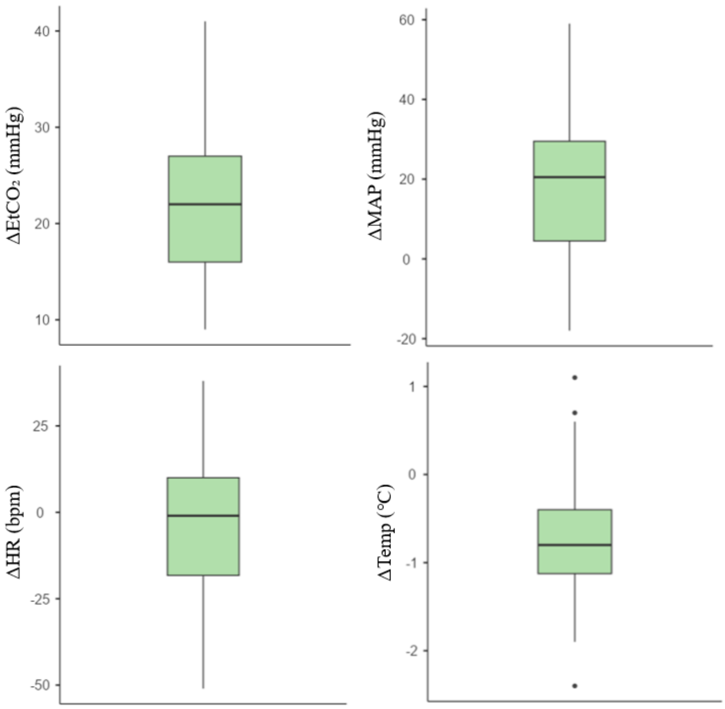

Figure 10. Changes in ventilatory and haemodynamic parameters induced by pneumoperitoneum, expressed as individual paired differences between baseline and pre-desufflation (T0 vs T4). Variables shown include end-tidal carbon dioxide ($\Delta EtCO_2$), mean arterial pressure (ΔMAP), heart rate (ΔHR), and body temperature (ΔTemp).

4.4 CUMULATIVE BLOOD GAS CHANGES INDUCED BY PNEUMOPERITONEUM (T0–T4)

Comparison of venous blood gas parameters between baseline (T0) and pre-desufflation (T4) revealed significant changes in several acid–base variables during pneumoperitoneum (Table 11, Figure 11). Venous pH decreased significantly from T0 to T4 ($p < 0.001$), while venous pCO_2 increased significantly over the same interval ($p < 0.001$). Bicarbonate (HCO_3^-) concentrations also showed a significant increase between T0 and T4 ($p < 0.001$).

In contrast, base excess did not differ significantly between the two time points ($p = 0.466$). Lactate concentrations increased modestly but significantly from baseline to T4 ($p = 0.013$).

Table 11. Comparison of venous blood gas variables between baseline (T0) and pre-desufflation (T4).

Parameter	T0 (mean ± SD)	T4 (mean ± SD)	Test	p-value
pH	7.269 ± 0.033	7.131 ± 0.066	Paired t-test	6.69×10^{-27}
pCO_2 (kPa)	6.00 ± 0.68	9.24 ± 1.69	Paired t-test	3.73×10^{-24}
HCO_3^- (mmol/L)	20.57 ± 1.68	22.87 ± 1.63	Paired t-test	3.11×10^{-20}
Base excess (mmol/L)	−6.41 ± 1.81	−6.33 ± 1.79	Wilcoxon signed-rank test	0.466
Lactate (mmol/L)	0.81 ± 0.65	1.15 ± 2.93	Wilcoxon signed-rank test	0.013

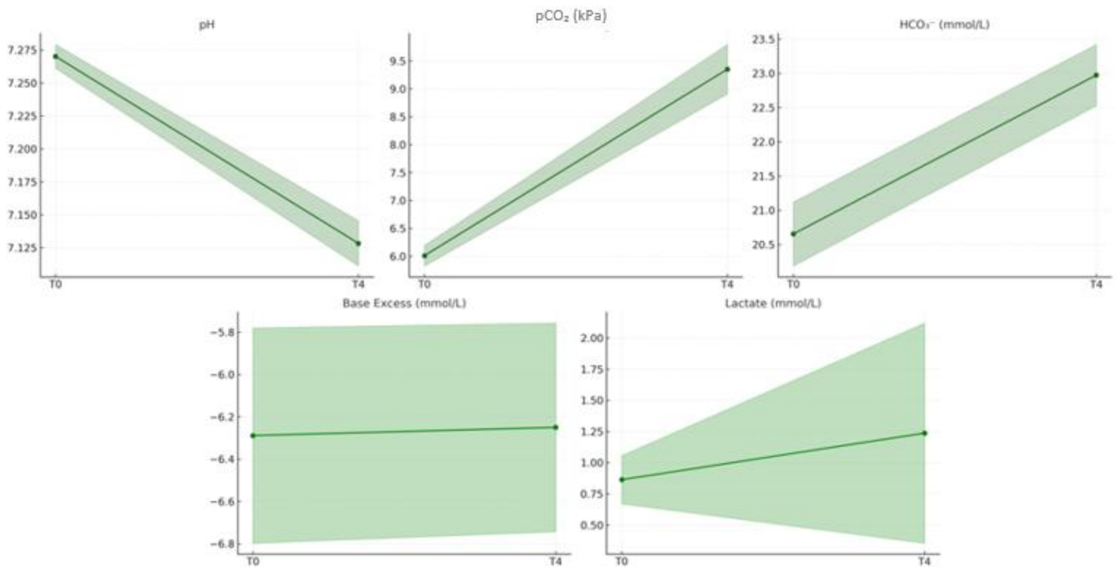

Figure 11. Venous blood gas changes from baseline (T0) to pre-desufflation (T4) during pneumoperitoneum. Mean values with 95% confidence intervals are shown for pH, pCO_2, HCO_3^-, base excess, and lactate.

4.5 EFFECT OF THORACIC CONFORMATION ON CUMULATIVE VENTILATORY AND HAEMODYNAMIC CHANGES (ΔT4–T0)

Cumulative changes in ventilatory variables between baseline (T0) and pre-desufflation (T4) were compared across thoracic conformation groups using individual paired differences (ΔT4–T0).

For ventilatory mechanics (Figure 12), dynamic compliance variation (ΔCdyn) did not differ significantly between thoracic conformation groups (Kruskal–Wallis χ^2 (2) = 3.30, p = 0.192). Likewise, airway resistance (ΔRrs) showed no significant between-group differences (χ^2 (2) = 1.11, p = 0.574).

Tidal volume variation (ΔVT, mL) showed a trend toward differences between thoracic conformations (χ^2 (2) = 5.19, p = 0.075). Dunn's post-hoc comparisons suggested less negative ΔVT values in chest shape 1 compared with chest shapes 2 (p = 0.053) and 3 (p = 0.067); however, these differences did not remain statistically significant after Bonferroni correction (all adjusted p > 0.15). Minute ventilation (ΔVm, $L \cdot min^{-1}$) did not differ significantly between thoracic conformation groups (χ^2 (2) = 1.39, p = 0.499), with no significant pairwise contrasts identified.

Peripheral oxygen saturation (ΔSpO_2) also showed no statistically significant differences across thoracic conformations (χ^2 (2) = 0.640, p = 0.726). Dunn's post-hoc analyses confirmed the absence of significant pairwise differences for all variables (all adjusted p > 0.05).

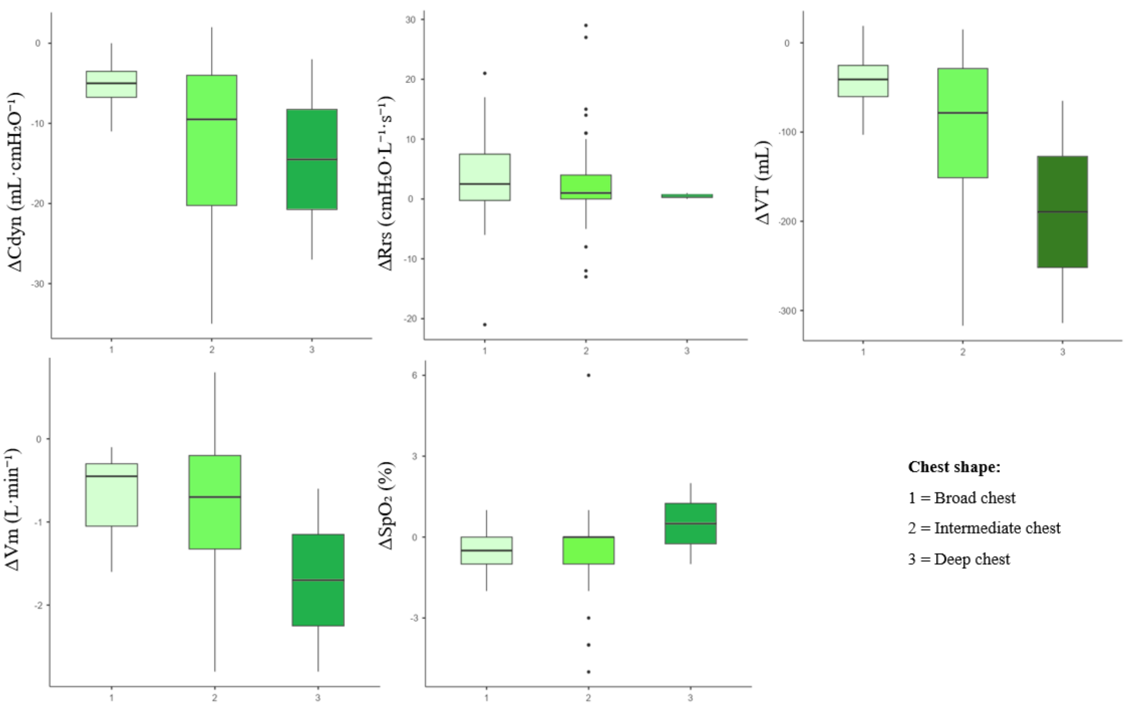

Figure 12. Boxplots representing cumulative ventilatory changes (ΔCdyn, ΔRrs, ΔVT, ΔVm, and ΔSpO_2), calculated as individual differences between baseline and pre-desufflation (ΔT4–T0), stratified by thoracic conformations.

Cumulative changes in haemodynamic and thermal parameters were analysed using one-way ANOVA (Figure 13). No significant effects of thoracic conformation were identified for end-tidal carbon dioxide variation ($\Delta EtCO_2$; $F(2, 61) = 0.687$, $p = 0.507$), mean arterial pressure (ΔMAP; $F(2, 61) = 0.593$, $p = 0.556$), heart rate (ΔHR; $F(2, 61) = 0.122$, $p = 0.885$), or body temperature (ΔTemperature; $F(2, 61) = 0.104$, $p = 0.901$). Tukey's post-hoc tests confirmed the absence of statistically significant pairwise differences for all haemodynamic variables.

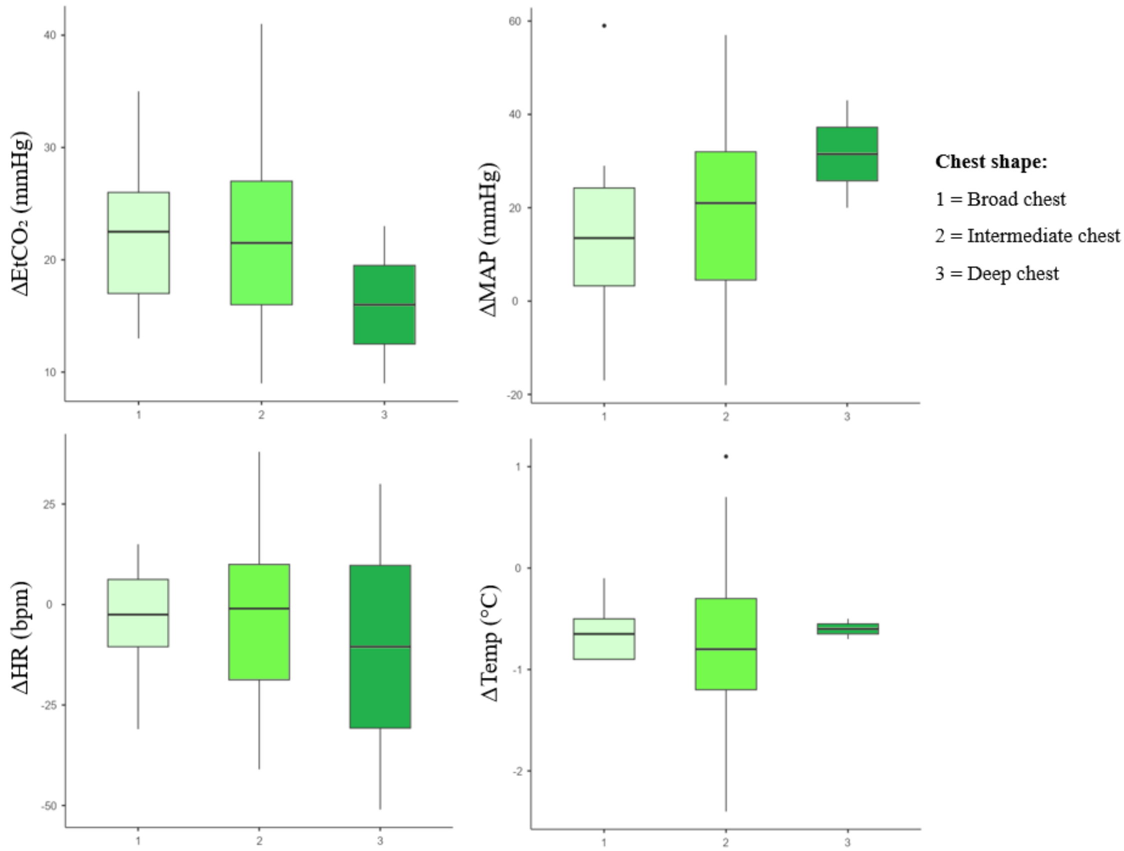

Figure 13. Boxplots representing cumulative haemodynamic and thermal changes between baseline and pre-desufflation (ΔT4–T0), stratified by thoracic conformation. Variables shown include $\Delta EtCO_2$, ΔMAP, ΔHR, and ΔTemperature

4.6 INFLUENCE OF THORACIC CONFORMATION ON CUMULATIVE GASOMETRIC CHANGES (ΔT4–T0)

Cumulative venous blood gas changes between T0 and T4 were assessed by calculating individual differences (ΔpH, ΔpCO_2, ΔHCO_3^-, ΔBE, and Δlactate) and comparing these across thoracic conformation groups (Figure 14).

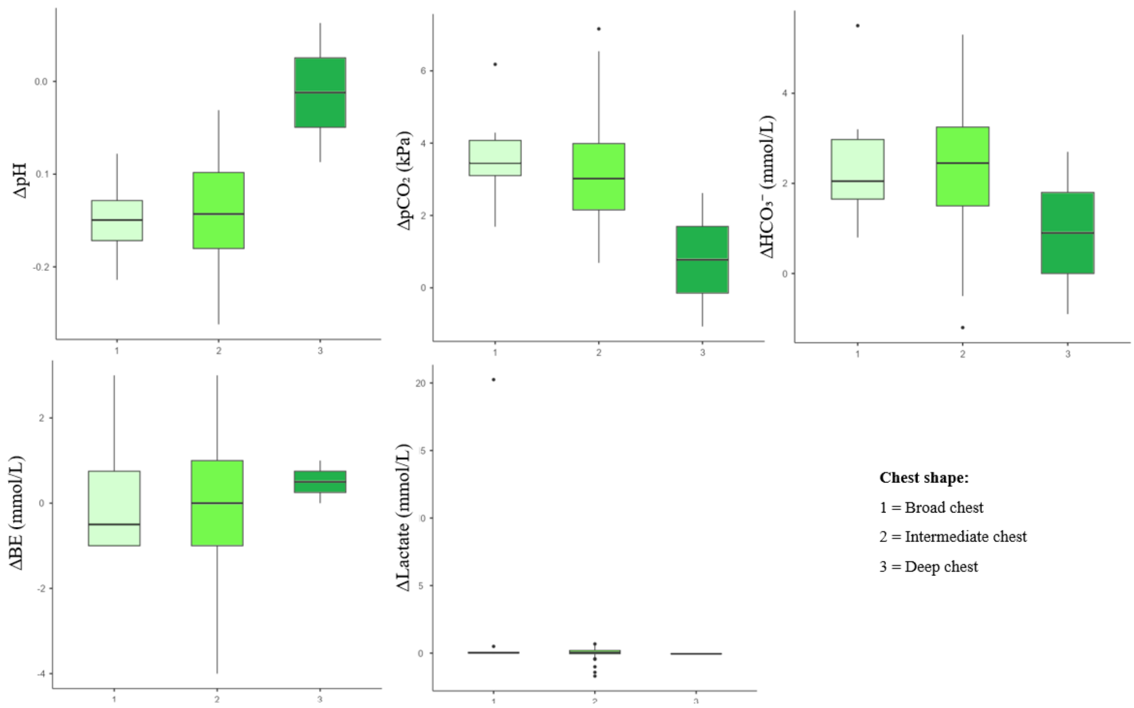

Figure 14. Boxplots of cumulative venous blood gas changes (ΔT4–T0), stratified by thoracic conformation (1 = broad-chested; 2 = intermediate; 3 = deep-chested). Variables shown include ΔpH, ΔpCO_2, ΔHCO_3^-, ΔBE, and Δlactate.

The cumulative change in pH (ΔpH) was normally distributed and analysed using one-way ANOVA, revealing a significant effect of thoracic conformation ($F (2, 61) = 5.18$, $p = 0.008$). Post-hoc Tukey analysis indicated that dogs classified as chest shape 3 exhibited significantly smaller reductions in pH compared with chest shapes 1 and 2 ($p < 0.01$), while no significant difference was observed between shapes 1 and 2.

Cumulative changes in carbon dioxide (ΔpCO_2), which were also normally distributed, did not differ significantly between thoracic conformation groups ($F (2, 61) = 2.83$, $p = 0.067$).

No significant between-group differences were observed for cumulative changes in bicarbonate (ΔHCO_3^-; $F (2, 61) = 1.10$, $p = 0.338$).

Variables ΔBE and Δlactate were non-normally distributed and analysed using the Kruskal–Wallis test. No significant differences were detected for ΔBE ($\chi^2 (2) = 0.55$, $p = 0.758$) or Δlactate ($\chi^2 (2) = 1.77$, $p = 0.41$), and no significant pairwise contrasts were identified on post-hoc testing.

4.7 TEMPORAL CHANGES FROM BASELINE TO POST-DESUFFLATION (T0 vs T5)

Because ventilatory and physiological variables met parametric assumptions, paired comparisons between baseline (T0) and post-desufflation (T5) were performed using paired *t*-tests (Table 12, Figure 17).

Regarding ventilatory mechanics, dynamic compliance (Cdyn) differed significantly between T0 and T5 ($t(63) = 3.53$, $p < 0.001$), while airway resistance (Rrs) also showed a significant change over time ($t(63) = -2.43$, $p = 0.018$). Tidal volume (VT) decreased significantly following desufflation ($t(63) = 3.76$, $p < 0.001$), as did minute ventilation (Vm) ($t(63) = 2.74$, $p = 0.008$). In contrast, peripheral oxygen saturation (SpO_2) did not differ significantly between T0 and T5 ($t(63) = -0.64$, $p = 0.527$).

Among gas exchange and haemodynamic variables, end-tidal carbon dioxide ($EtCO_2$) remained significantly higher at T5 compared with baseline ($t(63) = -12.86$, $p < 0.001$). Mean arterial pressure (MAP) increased significantly between T0 and T5 ($t(63) = -2.88$, $p = 0.005$), whereas heart rate (HR) showed a significant reduction over the same interval ($t(63) = 3.12$, $p = 0.003$). Body temperature also decreased significantly following desufflation ($t(63) = 10.92$, $p < 0.001$).

Table 12. Temporal changes in ventilatory and haemodynamic parameters from baseline (T0) to post-desufflation (T5).

Variable	Statistic	df	p-value
Cdyn ($mL \cdot cmH_2O^{-1}$)	$t = 3.53$	63	< 0.001
Rrs ($cmH_2O \cdot L^{-1} \cdot s^{-1}$)	$t = -2.43$	63	0.018
VT (mL)	$t = 3.76$	63	< 0.001
Vm (L·min)	$t = 2.74$	63	0.008
SpO_2 (%)	$t = -0.64$	63	0.527
$EtCO_2$ (mmHg)	$t = -12.86$	63	< 0.001
HR (bpm)	$t = 3.12$	63	0.003
MAP (mmHg)	$t = -2.88$	63	0.005
Temperature (°C)	$t = 10.92$	63	< 0.001

Note: All comparisons were performed using paired T-tests

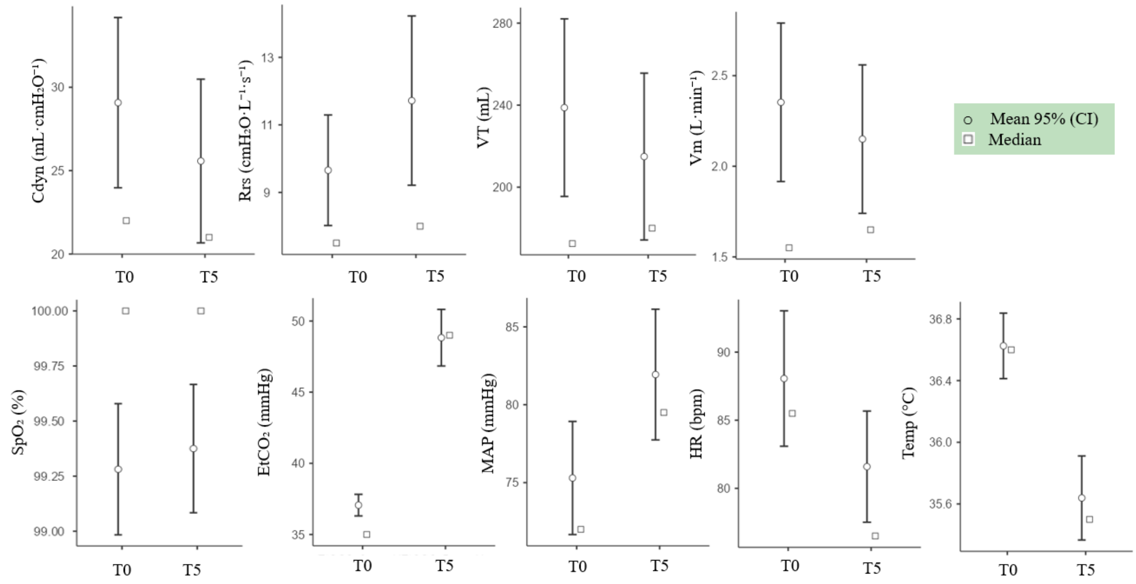

Figure 15. Temporal changes in ventilatory and haemodynamic parameters between baseline (T0) and post-desufflation (T5). Circles represent mean values with 95% confidence intervals, and squares indicate medians.

4.8 EFFECT OF THORACIC CONFORMATION ON POST-DESUFFLATION RECOVERY (ΔT5–T0)

The influence of thoracic conformation on early post-desufflation recovery (ΔT5–T0) was evaluated for ventilatory and physiological variables using individual paired differences, independently of the global temporal effects observed between baseline and post-desufflation (Table 13, Figure 18).

Table 13. Cumulative changes between baseline (T0) and post-desufflation (T5) across thoracic conformation groups.

Variable	Statistic	df	p-value
ΔCdyn (mL/cmH_2O)	χ^2 = 1.090	2	0.579
ΔRrs (cmH_2O·L^{-1}·s)	χ^2 = 1.410	2	0.493
ΔVT (mL)	χ^2 = 0.238	2	0.888
ΔVm (L·min)	χ^2 = 1.350	2	0.510
ΔSpO_2 (%)	χ^2 = 1.370	2	0.503
Δ$EtCO_2$ (mmHg)	F = 1.110	(2,61)	0.336
ΔMAP (mmHg)	F = 0.422	(2,61)	0.657
ΔHR (bpm)	χ^2 = 0.406	2	0.816
ΔTemp (°C)	χ^2 = 0.372	2	0.830

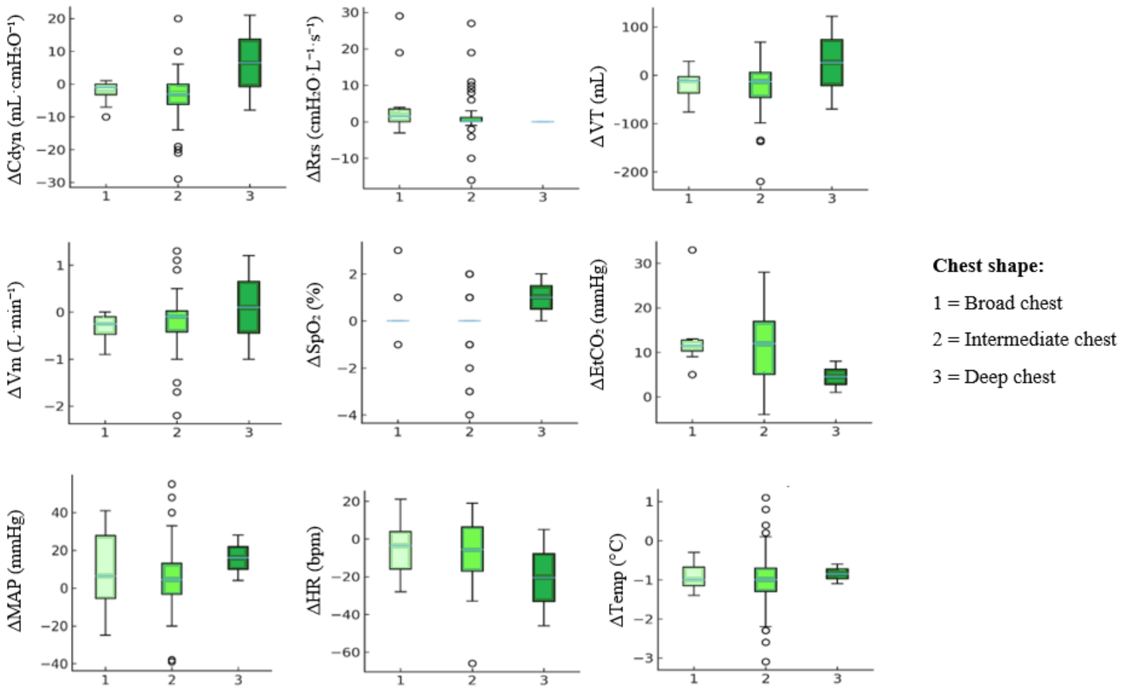

Figure 16. Distribution of post-desufflation changes (ΔT5–T0) in ventilatory, gas exchange, and haemodynamic variables across thoracic conformation groups. Boxplots represent the median and interquartile range, with whiskers extending to 1.5× the interquartile range and dots indicating outliers.

Regarding ventilatory mechanics, cumulative changes in dynamic compliance (ΔCdyn) did not differ significantly between thoracic conformation groups (Kruskal–Wallis χ^2 (2) = 1.09, p = 0.579). Similarly, airway resistance recovery (ΔRrs) was comparable across conformations (χ^2 (2) = 1.41, p = 0.493). Tidal volume variation (ΔVT) showed no significant between-group differences (χ^2 (2) = 0.238, p = 0.888), nor did minute ventilation (ΔVm; χ^2 (2) = 1.35, p = 0.510). Peripheral oxygen saturation (ΔSpO_2) also exhibited no significant differences across thoracic conformations (χ^2 (2) = 1.37, p = 0.503).

Gas exchange and haemodynamic parameters demonstrated similar post-desufflation recovery patterns across groups. End-tidal carbon dioxide variation ($\Delta EtCO_2$) did not differ significantly between thoracic conformations (one-way ANOVA: F (2, 61) = 1.11, p = 0.336). Mean arterial pressure changes (ΔMAP) were likewise comparable across groups (F (2, 61) = 0.422, p = 0.657). No significant differences were observed for heart rate (ΔHR; χ^2 (2) = 0.406, p = 0.816) or body temperature (ΔTemp; χ^2 (2) = 0.372, p = 0.830).

4.9 $EtCO_2$ NORMALISATION TIME AFTER DESUFFLATION: GLOBAL ANALYSIS

The time required for end-tidal carbon dioxide ($EtCO_2$) normalisation after desufflation showed marked interindividual variability. The distribution deviated significantly from normality (Shapiro–Wilk test, $p < 0.001$), showing right skewness and the presence of extreme values.

The median $EtCO_2$ normalisation time was 9 minutes (interquartile range [IQR]: 14.3 minutes), with values ranging from 1 to 50 minutes (Figure 15). These results demonstrate substantial interindividual variability in $EtCO_2$ normalisation time following desufflation across the study population.

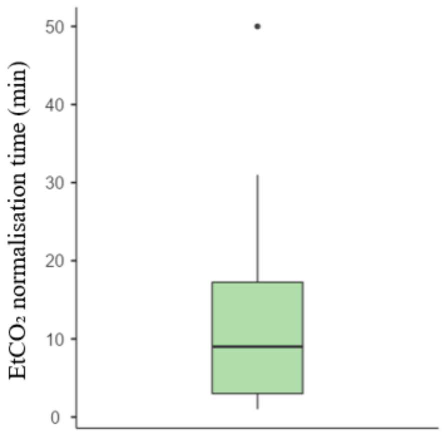

Figure 17. Distribution of end-tidal carbon dioxide ($EtCO_2$) normalisation time following desufflation in dogs undergoing laparoscopic pneumoperitoneum. Boxplots represent the median and interquartile range, with whiskers extending to 1.5× the interquartile range; dots indicate outliers. $EtCO_2$ normalisation time is expressed in minutes.

4.10 $EtCO_2$ NORMALISATION TIME AFTER DESUFFLATION ACCORDING TO THORACIC CONFORMATIONS

The time required for end-tidal carbon dioxide ($EtCO_2$) normalisation after desufflation was compared across thoracic conformation groups (Figure 16). Median normalisation times were 10.0 minutes for chest shape 1 (broad-chested), 9.5 minutes for chest shape 2 (intermediate), and 2.5 minutes for chest shape 3 (deep-chested), although the latter group included only two animals.

Shapiro–Wilk tests indicated non-normal distributions for chest shapes 1 ($p = 0.014$) and 2 ($p < 0.001$); therefore, between-group comparisons were performed using the Kruskal–Wallis test. No statistically significant differences were detected among thoracic conformation groups (χ^2 (2) = 4.15, $p = 0.126$). Dunn post-hoc comparisons with Bonferroni correction did not identify any significant pairwise differences (all adjusted p > 0.17).

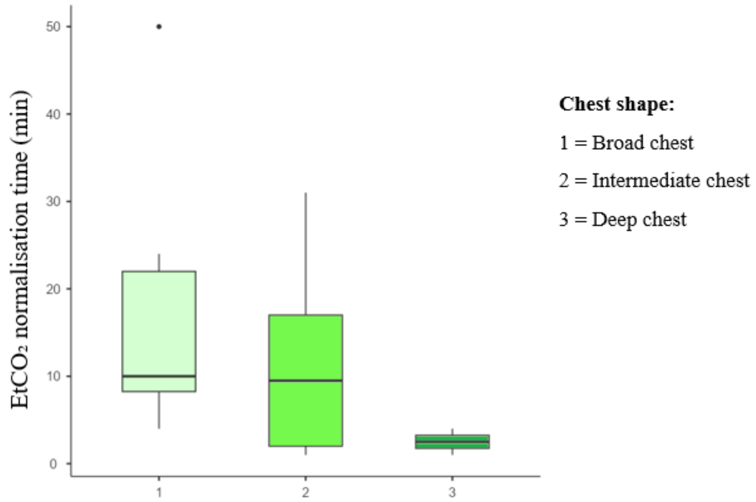

Figure 18. $EtCO_2$ normalisation time after desufflation stratified by thoracic conformation.

4.11 CORRELATION ANALYSES

A strong, positive, and statistically significant correlation was observed between cumulative changes in venous pCO_2 (ΔpCO_2, T4–T0; expressed in kPa) and end-tidal CO_2 ($\Delta EtCO_2$, T4–T0; mmHg). Pearson's correlation coefficient was $r = 0.687$ ($p < 0.001$), with a corresponding Spearman's ρ of 0.685 ($p < 0.001$) and a 95% confidence interval for Pearson's r ranging from 0.531 to 0.798 (Figure 20, panel A).

In contrast, no statistically significant association was observed between cumulative changes in dynamic compliance ($\Delta Cdyn$, T4–T0) and airway resistance (ΔRrs, T4–T0). Pearson's correlation coefficient was $r = 0.114$ ($p = 0.368$), and Spearman's ρ was 0.119 ($p = 0.350$), with a 95% confidence interval for Pearson's r ranging from −0.135 to 0.350 (Figure 20, panel B).

A strong and statistically significant correlation was also identified between body weight and baseline tidal volume (VT_0, mL). Pearson's correlation coefficient was $r = 0.944$ ($p < 0.001$), and Spearman's ρ was 0.948 ($p < 0.001$), with a 95% confidence interval for Pearson's r of 0.909–0.965 (Figure 19, panel C).

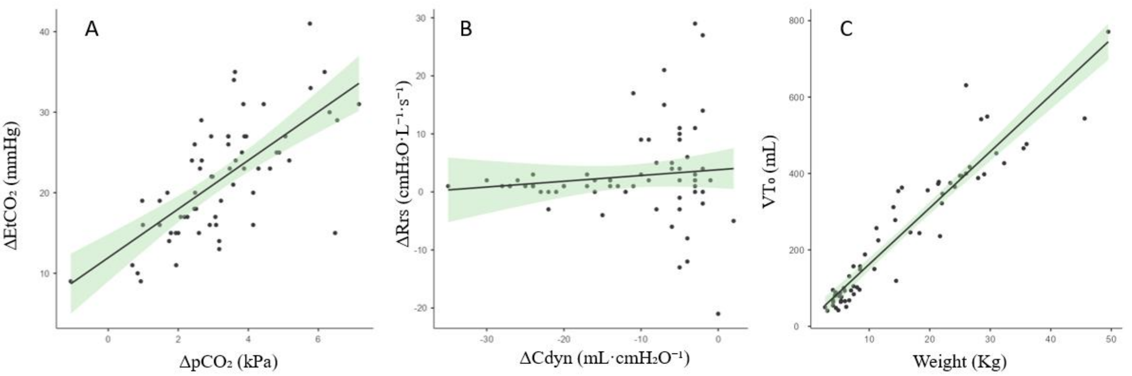

Figure 19. Scatterplots illustrating the relationships between cumulative changes in venous pCO_2 (ΔpCO_2, kPa) and end-tidal CO_2 ($\Delta EtCO_2$, mmHg) (A), cumulative changes in dynamic compliance (ΔCdyn) and airway resistance (ΔRrs) (B), and body weight and baseline tidal volume (VT_0, mL) (C). Shaded areas represent the 95% confidence intervals of the fitted regression lines.

4.12 LINEAR MIXED MODELS

Linear mixed-effects models were fitted to evaluate the effects of thoracic conformation (chest shape), time (T0–T5), and their interaction on ventilatory variables during pneumoperitoneum (Table 14, Figure 20). In all models, dog identity was included as a random intercept to account for repeated measures within subjects. Model convergence was achieved for all outcomes. Model fit was adequate across all outcomes, with high conditional R^2 values and substantial intraclass correlation coefficients (ICCs), supporting the inclusion of random effects.

4.12.1 DYNAMIC COMPLIANCE (Cdyn)

A statistically significant main effect of thoracic conformation on dynamic compliance was observed ($F(2, 61) = 6.35$, $p = 0.003$), indicating differences in Cdyn between chest shape groups. Time also exerted a significant effect ($F(5, 305) = 31.66$, $p < 0.001$), with dynamic compliance decreasing progressively over the course of pneumoperitoneum. A significant chest shape × time interaction was identified ($F(10, 305) = 4.07$, $p < 0.001$), indicating that the temporal pattern of compliance change differed across thoracic conformations. (Model fit: conditional $R^2 = 0.931$; marginal $R^2 = 0.223$; ICC = 0.911.)

4.12.2 END-TIDAL CARBON DIOXIDE ($EtCO_2$)

For end-tidal CO_2, a significant main effect of thoracic conformation was detected ($F(2, 61) = 3.52$, $p = 0.036$), indicating differences in overall $EtCO_2$ levels between chest shape groups. Time had a significant effect ($F(5, 305) = 33.42$, $p < 0.001$), with $EtCO_2$ increasing during pneumoperitoneum, reaching peak values between T3 and T4, and partially decreasing following desufflation at T5. The chest shape × time interaction was not statistically significant ($F(10, 305) = 0.45$, $p = 0.923$), indicating that the temporal trajectory of $EtCO_2$ change was comparable across thoracic conformation groups.
(Model fit: conditional $R^2 = 0.772$; marginal $R^2 = 0.544$; ICC = 0.501.)

4.12.3 AIRWAY RESISTANCE (Rrs)

No statistically significant main effect of thoracic conformation on airway resistance was observed ($F(2, 61) = 2.58$, $p = 0.084$), nor was there a significant effect of time ($F(5, 305) = 0.51$, $p = 0.770$). The interaction between thoracic conformation and time was also not significant ($F(10, 305) = 0.71$, $p = 0.715$), indicating that Rrs remained relatively stable throughout the study period and across chest shape groups. (Model fit: conditional $R^2 = 0.749$; marginal $R^2 = 0.071$; ICC = 0.730.)

4.12.4 TIDAL VOLUME (VT, mL)

A significant main effect of thoracic conformation on tidal volume was identified ($F(2, 61) = 6.17$, $p = 0.004$), reflecting differences in VT among chest shape groups. Time also exerted a significant effect ($F(5, 305) = 39.32$, $p < 0.001$), with VT decreasing during pneumoperitoneum and partially recovering following desufflation at T5. A significant chest shape × time interaction was observed ($F(10, 305) = 5.29$, $p < 0.001$), indicating that the magnitude of VT change over time differed according to thoracic conformation. (Model fit: conditional $R^2 = 0.940$; marginal $R^2 = 0.215$; ICC = 0.924.).

Table 14. Linear mixed-effects model results for ventilatory variables during pneumoperitoneum.

Outcome	R^2 Marginal	R^2 Conditional	Effect of Time	Effect of Chest Shape	Interaction Time × Chest Shape
Cdyn ($mL \cdot cmH_2O^{-1}$)	0.223	0.931	$F(5,305) = 31.66$, $p < 0.001$	$F(2,61) = 6.35$, $p = 0.003$	$F(10,305) = 4.07$, $p < 0.001$
$EtCO_2$ (mmHg)	0.544	0.772	$F(5,305) = 33.42$, $p < 0.001$	$F(2,61) = 3.52$, $p = 0.036$	$F(10,305) = 0.45$, $p = 0.923$
Rrs ($cmH_2O \cdot L^{-1} \cdot s^{-1}$)	0.071	0.749	$F(5,305) = 0.51$, $p = 0.770$	$F(2,61) = 2.58$, $p = 0.084$	$F(10,305) = 0.71$, $p = 0.715$
VT (mL)	0.215	0.940	$F(5,305) = 39.32$, $p < 0.001$	$F(2,61) = 6.17$, $p = 0.004$	$F(10,305) = 5.29$, $p < 0.001$

Note. Linear mixed-effects models included Time, thoracic conformation (Chest shape), and their interaction as fixed effects, with dog identity included as a random intercept. Marginal R^2 reflects variance explained by fixed effects, whereas conditional R^2 includes both fixed and random effects.

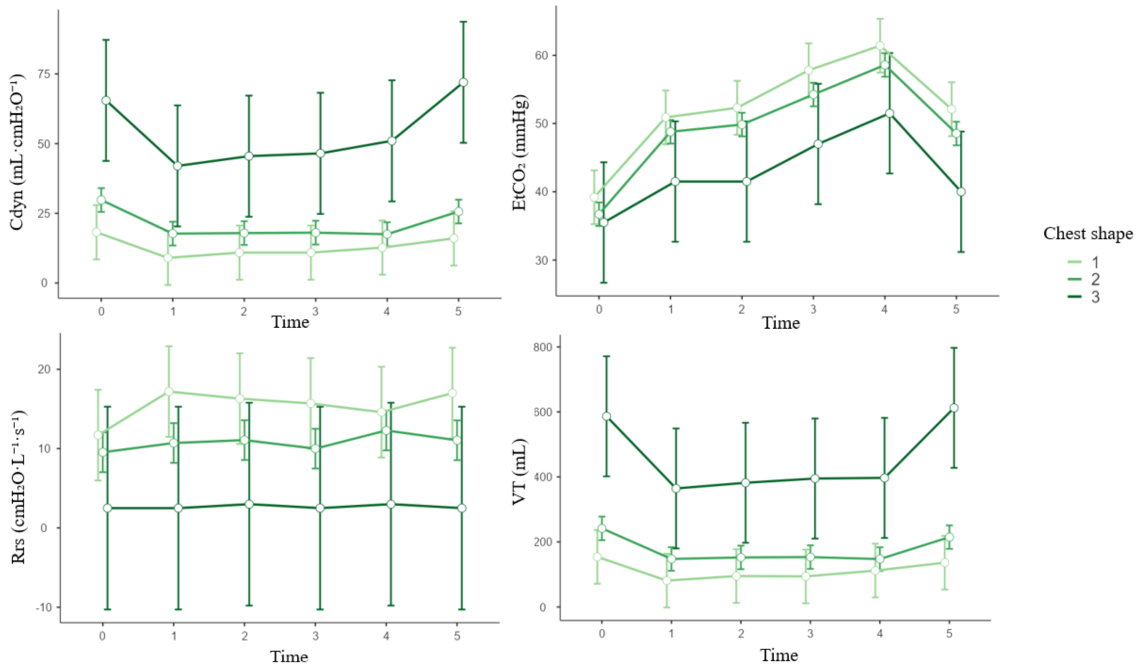

Figure 20. Longitudinal changes in ventilatory variables expressed as estimated marginal means (EMMs) ± 95% confidence intervals from T0 to T5 during pneumoperitoneum, stratified by thoracic conformation, as estimated using linear mixed-effects models. Chest shape groups were defined as: 1 = broad chest, 2 = intermediate chest, and 3 = deep chest.

5. DISCUSSION

The present study confirms that pneumoperitoneum (PNP) induces consistent and clinically relevant alterations in respiratory system mechanics and carbon dioxide handling in dogs undergoing laparoscopy, even under controlled mechanical ventilation and within intra-abdominal pressure (IAP) levels generally considered safe in small animal practice. This aligns with extensive evidence from human and veterinary anesthesia indicating that CO_2 insufflation imposes a predictable mechanical burden on the respiratory system (Odeberg-Wernerman, 2000; Kaba & Joris, 2001; Gerges et al., 2006; Atkinson et al., 2017; Scott et al., 2020). By integrating continuous spirometry, venous blood gas analysis, correlation testing, and longitudinal mixed-effects modelling, the current work strengthens the physiological interpretation of these changes and provides clinically applicable insights for intraoperative monitoring.

5.1 GLOBAL VENTILATORY AND HAEMODYNAMIC EFFECTS OF PNEUMOPERITONEUM

The onset of pneumoperitoneum is known to induce cranial displacement of the diaphragm, reduction of functional residual capacity (FRC), increased chest wall elastance, and ventilation–perfusion mismatch (Fahy et al., 1995; Pelosi et al., 1996). These mechanisms typically translate into increased airway pressures, reduced respiratory system compliance, and impaired carbon dioxide elimination (Bardoczky et al., 1993; Pelosi et al., 1996). In agreement with these established patterns, the present study demonstrated significant cumulative reductions in tidal volume, minute ventilation, and dynamic compliance, accompanied by increased airway resistance and progressive elevations in end-tidal CO_2 during pneumoperitoneum. Collectively, these findings support the concept that pneumoperitoneum imposes a predominantly elastic mechanical burden on the respiratory system, with a concomitant resistive component.

This global ventilatory profile is consistent with observations from human laparoscopy, in which pneumoperitoneum represents a major determinant of impaired ventilatory performance (Koivusalo & Lindgren, 2000; Sprung et al., 2002), as well as veterinary studies describing comparable mechanical constraints during minimally invasive procedures (Fantoni et al., 2016; Fransson & Mayhew, 2022). The longitudinal design of the present study further supports pneumoperitoneum as a dynamic physiological stressor, with cumulative effects that evolve over time rather than representing a simple binary exposure.

From a haemodynamic perspective, pneumoperitoneum was associated with a significant increase in mean arterial pressure, consistent with increased systemic vascular resistance and neurohumoral responses to elevated intra-abdominal pressure (Park & Okano., 2015; Atkinson et al., 2017; Ortenzi et al., 2022; Fitzgerald et al., 1992). Heart rate remained relatively stable, suggesting preserved autonomic balance in this cohort of healthy dogs under controlled anaesthetic conditions. Although a small but statistically significant change in peripheral oxygen saturation was observed, oxygenation remained clinically preserved, supporting the concept that, at moderate intra-abdominal pressure levels, the predominant intraoperative disturbance is mechanical and carbon dioxide–related rather than hypoxaemic (Koivusalo & Lindgren, 2000; Scott et al., 2020).

The progressive reduction in body temperature observed over time likely reflects the cumulative physiological impact of prolonged anaesthesia and surgical exposure. In addition to well-recognised anaesthesia-related mechanisms—such as peripheral vasodilation, reduced metabolic heat production, and impaired thermoregulatory control—the use of non-heated and non-humidified carbon dioxide for pneumoperitoneum may have contributed to intraoperative heat loss (Scott et al., 2020). Insufflation of cold, dry CO_2 promotes convective and evaporative heat exchange at the peritoneal surface, particularly during prolonged procedures, reinforcing the multifactorial nature of perioperative hypothermia during laparoscopic surgery.

5.2 INFLUENCE OF THORACIC CONFORMATION ON VENTILATORY AND HAEMODYNAMIC RESPONSES

A central contribution of this study is the demonstration that thoracic conformation modulates the magnitude and temporal evolution of ventilatory impairment induced by pneumoperitoneum. Differences in chest wall geometry are known to influence respiratory system elastance and the distribution of ventilation during mechanical ventilation (Xu et al., 2025). In human laparoscopy, abrupt reductions in respiratory compliance of approximately 20% have been reported at mean intra-abdominal pressure levels around 11 mmHg, with more pronounced effects at higher pressures (Oikkonen & Tallgren, 1995; Obeid et al., 1995).

In veterinary medicine, direct evidence specifically addressing the role of thoracic conformation remains limited. Nevertheless, the present findings are consistent with those reported by Asorey et al. (2020), who identified approximately 20% lower respiratory system compliance in barrel-chested dogs, potentially attributable to increased chest wall stiffness and a greater propensity for atelectasis formation. In the current study, cumulative ventilatory changes showed numerical trends toward greater tidal volume reduction in intermediate- and deep-chested dogs; however, these differences did not reach statistical significance after correction. This observation highlights the complexity and interindividual variability of ventilatory adaptation during pneumoperitoneum, even within morphologically defined subgroups.

From a physiological perspective, the chest wall constitutes a composite mechanical system encompassing the rib cage, diaphragm, abdominal contents, and abdominal wall, with dynamic interactions that vary according to body configuration and positioning (Fahy et al., 1995; Xu et al., 2025). It is therefore plausible that deep-chested morphotypes may better preserve effective thoracic expansion during increases in intra-abdominal pressure, whereas broader conformations experience proportionally greater mechanical restriction. Clinically, this may manifest as increased elastic load and reduced ventilatory efficiency. These interpretations align with evidence that morphofunctional characteristics, including body weight and thoracic geometry, influence respiratory mechanics in mechanically ventilated dogs (Bradbrook et al., 2013). Discrepancies with fluoroscopic studies reporting limited conformation-related effects may be explained by smaller sample sizes, static imaging conditions, or differences in morphometric classification methods (Chan et al., 2017).

Despite these ventilatory differences, their physiological impact did not translate into measurable haemodynamic instability. When haemodynamic and systemic variables were analysed, thoracic conformation did not significantly influence cumulative changes in end-tidal carbon dioxide, heart rate, mean arterial pressure, or body temperature. This absence of haemodynamic modulation suggests that, under moderate intra-abdominal pressure levels and controlled anaesthetic conditions, the impact of thoracic morphology is predominantly mechanical and ventilatory rather than cardiovascular. Importantly, the lack of conformation-related haemodynamic effects represents a clinically relevant finding, indicating preserved cardiovascular tolerance to pneumoperitoneum across thoracic morphotypes in healthy dogs.

Although breed-specific analysis was not a primary objective, the observation of abrupt ventilatory changes in some Dachshunds remains clinically relevant. While anecdotal, this finding reinforces the concept that certain breed-associated morphologies may limit tolerance to increases in intra-abdominal pressure and that within-breed variability, combined with classification sensitivity to respiratory phase and positioning, contributes to physiological heterogeneity (Filho et al., 2021; Soeratanapant et al., 2024). Thoracic conformation should therefore be interpreted as a contextual modifier of physiological response rather than a deterministic risk label.

5.3 ACID-BASE AND GASOMETRIC CONSEQUENCES OF PNEUMOPERITONEUM

Venous blood gas analysis confirmed the development of a mild and predominantly respiratory acid–base disturbance during pneumoperitoneum, characterised by a significant decrease in pH and a concomitant increase in pCO_2. This pattern is consistent with increased peritoneal absorption of carbon dioxide combined with reduced alveolar ventilation efficiency secondary to decreased respiratory system compliance (McMahon et al., 1993; Koivusalo & Lindgren, 2000; Iwasaka et al., 1996).

The observed increase in bicarbonate concentration, together with the relative stability of base excess, is compatible with early buffering and partial compensatory mechanisms rather than a primary metabolic disturbance (Silverstein & Hopper, 2015). Lactate concentrations remained low throughout the study, supporting the absence of clinically relevant hypoperfusion and aligning with previous reports indicating that low-to-moderate intra-abdominal pressure levels typically induce transient and reversible physiological changes in stable patients (Dexter et al., 1997; Gutt et al., 2004; Joshipura et al., 2009; Ortenzi et al., 2022).

When cumulative gasometric changes were analysed according to thoracic conformation, a significant effect was identified for ΔpH, with deep-chested dogs exhibiting smaller reductions in pH compared with broad- and intermediate-chested animals. Although this finding suggests a modest protective influence of deep thoracic morphology on acid–base balance during pneumoperitoneum, its interpretation should be approached with caution due to the limited sample size within conformation subgroups, particularly the small number of deep-chested animals. This trend may reflect more favourable thoracoabdominal mechanics and preservation of effective ventilation; however, confirmation in larger and more diverse populations is warranted. In contrast, cumulative changes in pCO_2, bicarbonate, base excess, and lactate did not differ significantly between thoracic conformation groups, indicating that thoracic morphology modulated the expression of acid–base disturbance without independently altering systemic carbon dioxide accumulation or metabolic status.

Methodologically, the use of jugular venous sampling represents a pragmatic and minimally invasive alternative to arterial puncture in veterinary anaesthesia. Under stable conditions, jugular venous values have been shown to reliably reflect arterial trends for pH and carbon dioxide, supporting their utility for monitoring acid–base evolution during anaesthesia (Ilkiw et al., 1991; Brandenburg & Dire, 1998; Larcher et al., 2023; Silverstein & Hopper, 2015). The strong association observed between cumulative changes in venous pCO_2 and end-tidal CO_2 further reinforces capnography as a reliable surrogate of systemic carbon dioxide burden during pneumoperitoneum (Wahba & Mamazza, 1993; Hirvonen et al., 1995).

5.4 POST-DESUFFLATION RECOVERY AND PERSISTENCE OF PHYSIOLOGICAL ALTERATIONS

Analysis of temporal changes from baseline to the immediate post-desufflation period demonstrated that several ventilatory and physiological variables did not return promptly to pre-insufflation values, consistent with previous experimental and clinical observations in laparoscopic surgery (Bardoczky et al., 1993; Gerges et al., 2006; Oikkonen & Tallgren, 1995). At the post-desufflation timepoint (T5), dynamic compliance, tidal volume, and minute ventilation remained significantly reduced compared with baseline, indicating persistence of mechanical impairment beyond the active pneumoperitoneum phase. This finding supports the concept that pneumoperitoneum induces not only acute but also residual alterations in respiratory system mechanics, likely related to sustained diaphragmatic displacement, incomplete alveolar recruitment, and delayed reversal of atelectatic regions (Bardoczky et al., 1993; Oikkonen & Tallgren, 1995).

At this same post-desufflation timepoint, end-tidal carbon dioxide remained significantly elevated relative to baseline, indicating that removal of intra-abdominal pressure does not result in immediate normalisation of carbon dioxide elimination. Persistent hypercapnia following desufflation has been attributed to ongoing release of stored CO_2 from peripheral tissues, continued peritoneal absorption, and a delayed equilibration of carbon dioxide kinetics, particularly when ventilatory settings are intentionally maintained constant (Hofer et al., 2002; Zuckerman & Heneghan, 2002). These observations reinforce that post-desufflation physiology represents a transitional state rather than an abrupt return to baseline homeostasis.

Haemodynamic variables also exhibited residual changes after desufflation. Mean arterial pressure remained elevated, while heart rate was reduced compared with baseline, suggesting continued autonomic and vascular modulation following pneumoperitoneum. This pattern likely reflects a combination of residual sympathetic activation, altered venous return dynamics, and the ongoing influence of anesthetic depth, as previously described in both human and veterinary laparoscopic models (Atkinson et al., 2017; Koivusalo & Lindgren, 2000). In parallel, body temperature continued to decline after desufflation, consistent with the cumulative effects of prolonged anesthesia and surgical exposure, compounded by the use of non-heated and non-humidified carbon dioxide, which promotes convective and evaporative heat loss during laparoscopic procedures (Ott, 1999; Sammour et al., 2010).

Importantly, when immediate post-desufflation recovery was analysed according to thoracic conformation, no significant differences were identified across ventilatory, gas exchange, or haemodynamic variables. Despite the demonstrated influence of thoracic morphology on intraoperative ventilatory mechanics, early recovery patterns at T5 appeared comparable between conformational groups. This dissociation suggests that while thoracic conformation modulates the magnitude and temporal evolution of ventilatory impairment during pneumoperitoneum, the immediate post-desufflation state is predominantly governed by systemic physiological factors rather than chest wall morphology alone.

Clinically, these findings emphasise that the post-desufflation period constitutes a distinct physiological phase requiring continued vigilance. The persistence of ventilatory and gas exchange alterations supports ongoing capnographic and spirometric monitoring during early recovery and cautions against assuming immediate physiological normalisation following abdominal decompression (Fantoni & Cortopassi, 2016; Scott et al., 2020).

5.5 RECOVERY DYNAMICS AND $EtCO_2$ NORMALISATION AFTER DESUFFLATION

Beyond the residual physiological alterations observed immediately after desufflation, analysis of the temporal dynamics of carbon dioxide elimination provides additional insight into post-pneumoperitoneum recovery. End-tidal CO_2 progressively declined following desufflation but did not normalise uniformly across individuals, consistent with the established kinetics of carbon dioxide absorption and elimination during laparoscopic procedures (Bardoczky et al., 1993; Pelosi et al., 1996). Because ventilatory settings were intentionally maintained constant to ensure comparability between groups, the persistence of elevated $EtCO_2$ values underscores the principle that increased minute ventilation is often required to offset CO_2 uptake during pneumoperitoneum (Tan et al., 1992; McMahon et al., 1993; Duke et al., 1996; Hirvonen et al., 1995; Wahba & Mamazza, 1993).

Marked interindividual variability in $EtCO_2$ normalisation time was observed, with recovery ranging from rapid normalisation to prolonged persistence of hypercapnia. This wide dispersion highlights the multifactorial nature of CO_2 elimination, which extends beyond residual mechanical impairment and reflects factors such as tissue CO_2 storage, perfusion, and individual metabolic characteristics (Gallagher et al., 1992).

When stratified by thoracic conformation, no statistically significant differences in $EtCO_2$ normalisation time were identified, despite numerical trends toward faster recovery in deep-chested dogs. The absence of significance likely reflects the limited sample size within conformation subgroups—particularly the small number of deep-chested animals—as well as substantial overlap between conformations. These findings indicate that although thoracic conformation modulates intraoperative ventilatory mechanics, it does not independently govern the kinetics of post-desufflation carbon dioxide elimination under conservative intra-abdominal pressure levels and controlled ventilatory conditions.

From a clinical perspective, the pronounced variability in $EtCO_2$ normalisation time reinforces the need for continued capnographic monitoring after desufflation and cautious timing of extubation. Particular attention should be given to patients exhibiting delayed CO_2 wash-out or individual characteristics that may predispose to residual hypercapnia, supporting a patient-specific rather than protocol-driven approach to recovery management (Harter, 2014).

5.6 INTEGRATIVE INSIGHTS FROM CORRELATION ANALYSES

Correlation analyses provided important physiological validation of the ventilatory and gasometric findings observed during pneumoperitoneum. The strong and statistically significant association between cumulative changes in venous pCO_2 and end-tidal CO_2 confirms that capnography reliably reflected systemic carbon dioxide burden under the study conditions, consistent with previous reports demonstrating good agreement between $EtCO_2$ and systemic carbon dioxide tension in anaesthetised dogs under stable haemodynamic conditions (Ilkiw et al., 1991; Brandenburg & Dire, 1998). This finding reinforces the clinical utility of continuous capnographic monitoring for tracking CO_2 kinetics during laparoscopic procedures, particularly in settings where arterial blood gas analysis is impractical or not routinely performed (Fantoni & Cortopassi, 2016).

In contrast, the absence of a significant correlation between cumulative changes in dynamic compliance and airway resistance underscores that these variables represent distinct mechanical components of the respiratory system. Dynamic compliance primarily reflects elastic properties of the integrated lung–chest wall–abdominal system, whereas airway resistance is more closely related to airway calibre and intrathoracic geometry, as classically described in respiratory physiology (West, 2012). Clinically, this dissociation highlights that reductions in tidal volume or compliance during pneumoperitoneum should not be interpreted as surrogate markers of increased airway resistance, emphasising the importance of direct spirometric assessment when ventilatory impairment is suspected.

The strong correlation observed between body weight and baseline tidal volume further confirms expected physiological scaling relationships in mechanically ventilated dogs. This finding supports the interpretation of absolute tidal volume values in the context of body size and reinforces the need for individualised ventilatory assessment rather than reliance on fixed settings alone.

Collectively, these correlation patterns strengthen the internal physiological coherence of the monitoring strategy employed and support the complementary integration of spirometry, capnography, and venous blood gas analysis for comprehensive intraoperative respiratory evaluation.

5.7 LONGITUDINAL INSIGHTS FROM LINEAR MIXED-EFFECTS MODELS

The application of linear mixed-effects models provided a robust framework for analysing dynamic ventilatory changes over time while accounting for repeated measurements and substantial interindividual variability, as recommended for longitudinal physiological data with hierarchical structure (Verbeke & Molenberghs, 2000; Brown & Prescott, 2015). The consistent and significant effect of time on dynamic compliance, tidal volume, and end-tidal CO_2 confirms that pneumoperitoneum induces progressive rather than static alterations in respiratory mechanics and gas exchange. This temporal behaviour reinforces the concept that pneumoperitoneum should be viewed as a sustained physiological stressor, with cumulative effects that evolve throughout the procedure rather than resolving instantaneously (Gerges et al., 2006; Atkinson et al., 2017).

Importantly, significant interactions between thoracic conformation and time were identified for dynamic compliance and tidal volume. These findings indicate that thoracic morphology influences not only the magnitude of ventilatory impairment but also the trajectory through which respiratory mechanics deteriorate during sustained intra-abdominal pressure. From a clinical perspective, this suggests that patients with less mechanically favourable thoracic conformations (i.e., those with lower thoracic depth-to-width ratios, particularly broad- and intermediate-chested dogs) may experience earlier or more pronounced declines in compliance and tidal volume, even when ventilatory settings remain unchanged, underscoring the need for anticipatory monitoring and timely ventilatory adjustment.

Conversely, the absence of a significant time × thoracic conformation interaction for end-tidal CO_2 suggests that carbon dioxide kinetics follow a broadly similar temporal pattern across thoracic morphotypes. This finding supports the interpretation that CO_2 elimination during and after pneumoperitoneum is governed predominantly by systemic factors—such as peritoneal absorption, tissue CO_2 storage, and perfusion—rather than by thoracic morphology alone, as previously described in experimental and clinical laparoscopic settings (Hofer et al., 2002; Zuckerman & Heneghan, 2002). The lack of significant effects for airway resistance across time and conformations further reinforces that pneumoperitoneum-induced ventilatory impairment in this cohort was driven primarily by elastic mechanical constraints rather than resistive airflow limitation.

Clinically, the high conditional R^2 values and substantial intraclass correlation coefficients observed across models highlight the dominant contribution of individual-level variability to ventilatory responses. This observation is consistent with methodological frameworks emphasising the distinction between marginal and conditional variance in mixed-effects models and supports the interpretation that individual patient characteristics account for a substantial proportion of observed physiological variability (Nakagawa & Schielzeth, 2013). Together, these findings emphasise that continuous spirometric and capnographic monitoring, interpreted within a temporal framework, is essential for detecting clinically meaningful ventilatory changes and optimising respiratory management during laparoscopic procedures in dogs.

5.8 METHODOLOGICAL CONSIDERATIONS: INTRA-ABDOMINAL PRESSURE, POSITIONING, AND VENTILATORY STRATEGY

The decision to limit intra-abdominal pressure to a maximum of 10 mmHg remains consistent with current veterinary recommendations aimed at minimising cardiopulmonary compromise, as deleterious effects become more pronounced at pressures ≥12 mmHg (Mayhew, 2011; Dorn et al., 2017; Fransson & Mayhew, 2022). Similar principles are advocated in human surgery, where the lowest IAP compatible with adequate surgical exposure is recommended to reduce secondary physiological disturbances (Neudecker et al., 2002; Gutt et al., 2004; Ortenzi et al., 2022; Rashdan et al., 2023; Dexter et al., 1999). Importantly, reductions in cardiac output have been documented even at IAP levels of 10 mmHg, emphasising that low-pressure pneumoperitoneum does not equate to absence of physiological impact (Richardson & Trinkle, 1976).

Patient positioning likely amplified the mechanical effects of pneumoperitoneum. Dorsal recumbency increases cranial diaphragmatic displacement, contributing to reductions in functional residual capacity and respiratory compliance (Atkinson et al., 2006; de Baerdemaeker & Margarson, 2016). In both human and veterinary patients, additive adverse effects have been reported when pneumoperitoneum is combined with positional changes, including lateral tilting, with atelectasis formation persisting after repositioning in dogs (Hodgson et al., 1994; Park et al., 2015; Roux et al., 2016).

Pressure-controlled ventilation (PCV) was selected to limit peak airway pressures and accommodate dynamic changes in respiratory compliance during pneumoperitoneum, as supported by both human and veterinary literature (Carraretto et al., 2005; Fantoni et al., 2016; Vieira de Almeida et al., 2003; Zitzmann et al., 2023). Despite this strategy, significant reductions in tidal volume and compliance were observed, underscoring the limitations of fixed ventilatory settings in the presence of evolving mechanical constraints.

Continuous spirometric monitoring proved essential for detecting mechanically relevant changes that were not always apparent through conventional parameters such as end-tidal CO_2. Spirometry enabled real-time assessment of tidal volume delivery, airway resistance, compliance, and ventilatory loop morphology, facilitating differentiation between elastic and resistive components of respiratory impairment (Rozanski & Hoffman, 1999; Srivastava & Niranjan, 2010; Calice & Moens, 2016). This approach complemented capnography and venous blood gas analysis by supporting ventilatory interpretation and adjustment based on objective mechanical behaviour rather than $EtCO_2$ trends alone (Moens, 2010; Calice & Moens, 2016).

5.9 CLINICAL RELEVANCE FOR VETERINARY NURSING

From a clinical perspective, this study highlights the central role of the veterinary nurse in advanced intraoperative monitoring during laparoscopic procedures. Continuous spirometric monitoring enabled early detection of mechanically relevant changes, such as reductions in compliance and tidal volume, that were not always immediately reflected by conventional parameters such as $EtCO_2$ or peripheral oxygen saturation (Rozanski & Hoffman, 1999; Calice & Moens, 2016).

Thoracic conformation provides valuable contextual information that can assist veterinary nurses in anticipating ventilatory responses during pneumoperitoneum. Broad-chested dogs may require closer surveillance, more conservative ventilatory pressures, and prolonged monitoring after desufflation, whereas deep-chested dogs appear more mechanically resilient yet still experience measurable impairment. The ability of veterinary nurses to interpret real-time spirometric data, recognise evolving trends, and communicate clinically relevant findings to the anesthetic team is therefore essential for timely adjustment of ventilatory strategies and optimization of patient safety (Hayden & Cowman, 2011; Calice & Moens, 2016).

5.10 LIMITATIONS AND FUTURE PERSPECTIVES

Several limitations of the present study should be acknowledged when interpreting its findings. The number of animals included was limited, and although thoracic conformation groups were balanced, a larger sample size would increase statistical power and improve the detection of subtle interaction effects. In addition, only healthy ASA I dogs were enrolled, which restricts the generalisability of the results to clinical patients with cardiopulmonary disease or reduced physiological reserve.

Blood gas analysis was performed using venous rather than arterial samples, a choice driven by feasibility and reduced invasiveness in a clinical setting, but one that provides less precise information regarding alveolar gas exchange. Furthermore, only moderate intra-abdominal pressure levels were examined, and higher pressures commonly used in some clinical contexts may produce different ventilatory responses.

Thoracic conformation classification based on depth-to-width ratios, although widely validated, maybe influenced by respiratory phase and body positioning, introducing potential misclassification variability (Buchanan & Bücheler, 1995; Buchanan, 2000; Filho et al., 2021; Soeratanapant et al., 2024). Moreover, extreme brachycephalic conformations were not represented in the study population, limiting extrapolation of these findings to such breeds.

Future research should therefore incorporate broader clinical populations, explore wider intra-abdominal pressure ranges, compare different ventilatory modes, and integrate regional ventilation assessment techniques to further elucidate atelectasis formation and ventilation distribution during pneumoperitoneum (Fransson & Mayhew, 2022; de Baerdemaeker & Margarson, 2016).

6. CONCLUSIONS

This study demonstrates that pneumoperitoneum during laparoscopic procedures in dogs induces consistent and clinically relevant alterations in respiratory system mechanics and carbon dioxide handling, even when conservative intra-abdominal pressure levels and controlled anesthetic strategies are employed. The observed ventilatory impairment was characterised primarily by progressive reductions in dynamic compliance and tidal volume, accompanied by cumulative carbon dioxide retention, supporting the interpretation that pneumoperitoneum predominantly increases the elastic load of the respiratory system rather than inducing a purely resistive limitation.

Thoracic conformation emerged as a relevant modifier of the magnitude and temporal evolution of these ventilatory changes. While thoracic morphology did not independently determine adverse gasometric or haemodynamic outcomes, it influenced respiratory mechanics and recovery dynamics, reinforcing its role as contextual information for anticipating intraoperative ventilatory behaviour rather than as a deterministic risk factor.

The integration of continuous spirometric monitoring with capnography and venous blood gas analysis provided complementary and physiologically coherent information throughout pneumoperitoneum. This multimodal monitoring approach enabled differentiation between mechanical restriction and airflow-related phenomena, supported accurate interpretation of ventilatory trends, and facilitated timely adjustments to ventilatory management that were not always apparent through conventional monitoring alone.

Overall, these findings support the incorporation of advanced respiratory monitoring strategies into the routine anesthetic management of veterinary laparoscopic procedures. Continuous spirometry, in particular, represents a valuable tool for enhancing intraoperative vigilance, individualising ventilatory support, and improving patient safety in small animals undergoing minimally invasive surgery.

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8. APPENDICES

APPENDIX I - Data Collection Form Used During the Study

HOSPITAL VETERINÁRIO SÃO BENTO

Estudo: Impact of Pneumoperitoneum on Ventilatory and Haemodynamic Function in Dogs
Local: Hospital Veterinário de São Bento
Período: Fevereiro – Outubro 2025

Formulário de Recolha de Dados

1. Identificação do paciente	
Paciente	
Data	
Raça	
Idade (anos)	
Peso (kg)	
Sexo	
ASA	
Procedimento realizado	

2. Caracterização morfométrica	
Altura do tórax (cm)	
Largura do tórax (cm)	
Rácio TD/TW	
Classificação torácica	☐ Largo (<0,75) ☐ Intermédio (0,75–1,25) ☐ Profundo (>1,25)
Superfície corporal (BSA) (m^2)	

3. Protocolo anestésico padronizado	
Parâmetros ventilatórios fixos	FR = 10 rpm | I:E = 1:2 | PEEP = 4 cmH_2O
Indução	Metadona 0,3 mg/kg • Dexmedetomidina 0,0025 mg/kg • Midazolam 0,2 mg/kg • Propofol (dose-efeito)
Manutenção	Isoflurano em O_2 a 40%
Ventilação mecânica	Modo PCV; Pressão inspiratória basal (cmH_2O) _____ ($EtCO_2$ 35–45 mmHg)
Fluidoterapia	5 mL/kg/h
Pneumoperitoneu	Pressão intra-abdominal fixa: 10 mmHg

4. Registo temporal do pneumoperitoneu	
Evento	Hora

Hospital Veterinário de São Bento | Formulário de Recolha de Dados | Uso exclusivo para investigação

Início do pneumoperitoneu	
Fim do pneumoperitoneu	
Normalização $EtCO_2$	

5. Pontos temporais de medição

Ponto	Descrição
T0	Valor basal após estabilização (15 min, PIA = 0 mmHg)
T1	5 min após pneumoperitoneu (PIA = 10 mmHg)
T2	Antes da inclinação dorsolateral 15° (PIA = 10 mmHg)
T3	5 min após inclinação dorsolateral 15° (PIA = 10 mmHg)
T4	Antes da desinsuflação (PIA = 10 mmHg)
T5	5 min após desinsuflação (PIA = 0 mmHg)

6. Parâmetros ventilatórios, hemodinâmicos e fisiológicos

Tempo	VT (mL)	Vm (L/min)	Cdyn (mL/cmH_2O)	Rrs (cmH_2O/L/s)	SpO_2 (%)	$EtCO_2$ (mmHg)	FC (bpm)	MAP (mmHg)	Temp (°C)
T0									
T1									
T2									
T3									
T4									
T5									

7. Gasometria venosa

Parâmetro	T0	T4	Valores de referência
pH			*7,32–7,44*
pCO_2			*3,5–6,0 kPa*
HCO_3^-			*16–26 mmol/L*
TCO_2			*16–26 mmol/L*
BE			*−9 a +1 mmol/L*
pO_2			*11,3–13,3 kPa*
sO_2			*95–100 %*
Lactato			*0,4–2,8 mmol/L*

Hospital Veterinário de São Bento | Formulário de Recolha de Dados | Uso exclusivo para investigação

APPENDIX II – Owner consent form (English)

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SÃO BENTO

Owner Consent Form

I, ___________________________________, owner of the dog _________________, with hospital registration number ______________, hereby authorize the collection and use of my animal's clinical data for academic research purposes in the master's thesis entitled "Impact of Pneumoperitoneum on Ventilatory and Haemodynamic Function in Dogs: Influence of Thoracic Conformation Assessed by Spirometry", developed at the Escola Superior Agrária de Viseu within the Master's Degree in Veterinary Nursing for Companion Animals.

Animal's Owner: ____

Date: ____ / ____ / ______

APPENDIX III – Termo de consentimento informado (Português)

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SÃO BENTO

Termo de Consentimento informado

Eu, ___________________________________, tutor(a) do cão _________________, com o número de registo hospitalar ______________, declaro autorizar a recolha e utilização dos dados clínicos do meu animal para fins de investigação académica na tese de mestrado intitulada: "Impact of Pneumoperitoneum on Ventilatory and Haemodynamic Function in Dogs: Influence of Thoracic Conformation Assessed by Spirometry", desenvolvida na Escola Superior Agrária de Viseu, no âmbito do Mestrado em Enfermagem Veterinária de Animais de Companhia.

Tutor(a) do animal: ____

Data: ____ / ____ / ______