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Pulmonary function testing in veterinary practice

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Abstract

Pulmonary function testing (PFT) comprises a group of objective diagnostic techniques used to evaluate respiratory mechanics and gas exchange, playing an increasingly important role in veterinary clinical practice. These tests provide quantitative assessment of lung function, aiding in the diagnosis, localization, and monitoring of respiratory disorders in small animals. This review outlines the principles, indications, and clinical applications of commonly used pulmonary function tests, including spirometry, tidal breathing flow-volume loops, lung compliance and resistance measurements, whole-body plethysmography, forced oscillation technique, and tests of pulmonary gas exchange such as arterial blood gas analysis, diffusing capacity, pulse oximetry, and capnography. Emphasis is placed on their utility in assessing obstructive and restrictive airway diseases, peri-anaesthetic respiratory function, and therapeutic responses. While many techniques are non-invasive and safe, appropriate patient selection and awareness of contraindications are essential for reliable results. Advances in equipment and testing protocols have improved the feasibility of performing these tests in conscious animals, enhancing their clinical relevance. Pulmonary function testing offers valuable insights into respiratory physiology and disease severity, supporting evidence-based diagnosis and optimized management of respiratory conditions in veterinary patients.

Keywords: Pulmonary function testing, veterinary respiratory medicine, spirometry

Introduction

Pulmonary function testing (PFT) constitutes a vital set of diagnostic procedures extensively utilized in human respiratory medicine, sports medicine, and occupational health. These tests objectively evaluate lung function by examining not only the large and small airways but also the pulmonary parenchyma, inclusive of the alveolar capillary bed. In veterinary medicine, particularly concerning small animals, PFTs serve multiple critical roles: assessing lung function in animals with suspected or confirmed respiratory disorders, aiding pre-anesthetic evaluations, guiding diagnosis, and monitoring therapeutic responses to optimize and tailor ongoing treatments.

Indications and Safety Considerations

While PFTs are generally safe and non-invasive, there are specific contraindications that must be observed to avoid potential risks. These contraindications include conditions such as pneumothorax, unexplained hemoptysis, hemodynamic instability especially related to pulmonary thromboembolism, recent surgical procedures involving the thoracic or abdominal cavities, recent ophthalmic surgeries, and the presence of infectious respiratory diseases. Importantly, the effectiveness of these tests relies heavily on patient cooperation and effort, with pain and discomfort in the thoracic or abdominal regions potentially compromising test quality.

Purpose and Classification of Pulmonary Function Tests

Fundamentally, pulmonary function tests are designed not to establish specific diagnoses but rather to quantify the degree of respiratory dysfunction. Additionally, in various cases, they assist in localizing the anatomical site of respiratory disease — differentiating whether the upper or lower airways are involved. Advances in veterinary technology and refinement in

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testing protocols have significantly lowered the barriers to performing PFTs accurately and safely in conscious small animals, making these tests increasingly accessible in clinical settings.

Pulmonary function tests are broadly categorized into two major groups

1. **Tests of Lung Mechanics:** These assess the physical properties of the lungs and airways by evaluating parameters such as airway pressure, airflow, and lung volumes.
2. **Tests of Pulmonary Gas Exchange:** These evaluate the efficiency of oxygen and carbon dioxide exchange between the lungs and bloodstream.

Tests of Lung Mechanics

Spirometry

Spirometry remains one of the simplest and most widely employed methods for assessing pulmonary function by measuring airflow volumes and rates during breathing cycles. It serves as the diagnostic standard for obstructive respiratory diseases in humans and is applied in veterinary medicine to diagnose disorders such as tracheal collapse, brachycephalic airway syndrome, and feline lower airway diseases. Additionally, it aids in assessing ventilatory function in animals with neuromuscular impairments or post-anaesthetic recovery.

In veterinary practice, spirometry is performed using handheld spirometers or pneumotachographs attached to either endotracheal tubes in anesthetized patients or tightly fitted masks in conscious animals. Due to challenges in instructing veterinary patients, tests typically measure spontaneous tidal volumes rather than forced vital capacity maneuvers common in humans.

Normal respiratory parameters for dogs and cats are well characterized, including tidal volume, respiratory rate, peak inspiratory and expiratory flows, and lung compliance values, which provide reference standards for clinical interpretation.

Tidal Breathing Flow-Volume Loops (TBFVL)

TBFVL are graphical representations plotting the dynamic relationship between airflow and lung volume during quiet breathing, allowing clinicians to detect airway obstructions. This technique caters particularly well to veterinary patients who cannot follow commands necessary for forced breathing maneuvers.

During TBFVL testing, animals are acclimated to remain calm and breathe normally through a well-fitted mask connected to flow sensors. The resulting flow-volume loops reveal both qualitative and quantitative data, including respiratory rate, inspiratory and expiratory flow rates at various tidal volumes, and timing metrics. This method effectively distinguishes fixed airway obstructions, like laryngeal masses causing flattening of both inspiratory and expiratory limbs of the loop, from dynamic obstructions such as tracheal collapse or partial laryngeal paralysis that predominantly affect the inspiratory phase.

This non-invasive and rapid screening tool correlates well with direct airway visualization via tracheoscopy, confirming its clinical utility in diagnosing tracheal and upper airway diseases.

Lung Compliance

Lung compliance reflects the elasticity or distensibility of lung tissue, expressed as the change in lung volume per unit

change in airway pressure, and is indicative of lung and thoracic wall mechanics. Measurement generally requires patients to be intubated with oesophageal pressure monitoring serving as a surrogate for pleural pressure.

Compliance is divided into

- **Static Compliance:** Evaluated during no airflow conditions (inspiratory hold), representing lung and chest wall elasticity without the influence of airway resistance.
- **Dynamic Compliance:** Measured during active breathing cycles, accounting for airway resistance and tissue elasticity.

Diseases such as acute respiratory distress syndrome (ARDS), pneumonia, pulmonary fibrosis, and pulmonary oedema result in reduced lung compliance, necessitating higher airway pressures to achieve adequate ventilation.

Lung Resistance

Lung resistance quantifies the pressure required to maintain airflow against airway narrowing or obstruction. It primarily reflects small airway patency and is elevated in obstructive respiratory conditions such as chronic bronchitis or asthma. Similar to compliance measurements, lung resistance assessments benefit from specialized equipment capable of precise airflow and pressure recordings.

Whole-Body Plethysmography

Considered the gold standard for measuring lung volumes, plethysmography quantifies total lung capacity, functional residual capacity, and residual volume. Traditional methods involving sealed chambers present challenges in animals due to intolerance of increased airway resistance; therefore, modifications such as head-out plethysmography and barometric whole-body plethysmography (BWBP) have been developed.

BWBP is a non-invasive method where the animal is enclosed within a sealed chamber that measures pressure oscillations from breathing-induced thoracic volume changes. It records parameters like respiratory rate, pseudo-flow rates, pseudo-volume, inspiratory and expiratory times, and provides surrogates for airway resistance using calculated indices such as enhanced pause (Penh).

This technique has found clinical applications in evaluating brachycephalic obstructive airway syndrome (BOAS) and in assessing airway responsiveness in both dogs and cats. Despite some sensitivity to movement artifacts, BWBP offers an effective, non-sedated diagnostic option for airway function evaluation.

Forced Oscillation Technique (FOT)

Widely used in human medicine but not yet extensively applied in veterinary practice, FOT assesses respiratory system impedance by applying low-frequency sound waves during tidal breathing. Different frequencies characterize large versus small airway function and lung parenchymal properties. Although it complements spirometry, its inability to differentiate between restrictive and obstructive lung disease limits its diagnostic specificity.

Tests of Pulmonary Gas Exchange

Diffusing Capacity of Carbon Monoxide (DLCO)

DLCO measures the efficiency of gas diffusion across the alveolar-capillary membrane by exploiting haemoglobin's high affinity for carbon monoxide in comparison to oxygen.

When lung volumes and spirometry appear normal but DLCO is reduced, impaired diffusion is indicated. This test is vital in diagnosing conditions like pulmonary arterial hypertension and interstitial lung disease in humans, though its use in veterinary medicine has been limited mostly to large animals.

Arterial Blood Gas Analysis

Arterial blood gas (ABG) analysis remains the gold standard for quantifying oxygenation and ventilation status in small animals. Blood is typically sampled from arteries such as femoral, dorsal metatarsal, aural, or sublingual arteries using pre-heparinized syringes with meticulous care to avoid contamination and sample degradation.

ABG testing provides key parameters including arterial oxygen tension (PaO_2), carbon dioxide tension (PaCO_2), blood pH, and derived acid-base indicators like bicarbonate concentration and base excess. Understanding the physiology behind hypoxemia (low PaO_2) requires considering factors such as reduced inspired oxygen fraction, ventilation-perfusion mismatch, intrapulmonary shunting, diffusion impairment, and hypoventilation.

Clinicians distinguish hypoxemia (low oxygen in blood) from hypoxia (insufficient oxygen at tissues) and further classify hypoxia into types including hypoxic, circulatory, anaemic, and histotoxic, each with distinct pathophysiology.

ABG data interpretation involves

- Assessing acid-base status (acidosis vs alkalosis and their metabolic or respiratory origins).
- Evaluating ventilation adequacy via PaCO_2 .
- Examining oxygenation via PaO_2 and derived measures like the alveolar-arterial oxygen gradient (A-a gradient) and $\text{PaO}_2/\text{FiO}_2$ ratio (PF ratio), which inform on the severity of pulmonary dysfunction.

The PF ratio is especially useful in grading acute lung injury (ALI) and acute respiratory distress syndrome (ARDS), aiding clinical decision-making based on oxygenation impairment severity.

Pulse Oximetry

Pulse oximetry is a non-invasive, widely available modality providing continuous assessment of haemoglobin oxygen saturation (SpO_2). It operates by differential light absorption at red and infrared wavelengths through perfused tissues, commonly utilizing clip or reflectance sensors placed on areas such as the tongue, ear, or tail base in small animals.

Though convenient and practical for monitoring oxygenation trends and detecting hypoxemia in real time, pulse oximetry offers an indirect measure and is influenced by the oxyhaemoglobin dissociation curve. Readings above 95% generally correspond with normal oxygenation, whereas values below 90% indicate potentially critical hypoxemia.

Limitations arise due to the inability to detect abnormal haemoglobin species (e.g., carboxyhaemoglobin, methaemoglobin) with standard devices, the influence of poor perfusion, anaemia, skin pigmentation, motion artifacts, and exposure to certain dyes or excessive ambient light.

Emerging pulse CO-oximeters utilize multiple wavelengths to differentiate various haemoglobin species, enhancing diagnostic accuracy in specific clinical scenarios.

End-Tidal Capnography

Capnography measures the partial pressure of carbon dioxide in exhaled breath (end-tidal CO_2 or EtCO_2), providing

instantaneous feedback on ventilatory status, especially valuable during anaesthesia, critical care, and resuscitation.

There are two main types of capnometers

- **Mainstream:** Sensor placed directly in the airway between endotracheal tube and breathing circuit.
- **Sidestream:** Gas sampled via tubing to a remote sensor, potentially incurring slight delays.

A normal capnographic waveform displays phases corresponding to dead space elimination, alveolar gas exhalation plateau, and inhalation. The EtCO_2 value approximates arterial CO_2 concentrations, with minor normal gradients due to anatomic dead space.

Capnography is essential for verifying correct endotracheal tube placement, monitoring ventilation adequacy, detecting respiratory abnormalities, and guiding mechanical ventilation. Increased gradients between PaCO_2 and EtCO_2 may indicate ventilation-perfusion mismatches or increased physiologic dead space.

Advanced volumetric capnography extends these capabilities by correlating CO_2 levels with exhaled volumes, offering breath-by-breath analysis of dead space and alveolar ventilation efficiency, although this remains under evaluation for veterinary application.

Conflict of Interest

Not available

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