

DEAD SPACE - Cause, Effect, & Control in Small Animal Anesthesia

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Dead space is an often misunderstood and overlooked aspect of veterinary anesthesia patient management. Dead space is always present as a component of the patient's airway and, to a variable degree, as a component of the anesthetic system. Ignoring the harmful consequences of system dead space can lead to potentially fatal patient outcomes. This is especially worrisome when managing small patients.

There are three different types of dead space: anatomic, alveolar, and mechanical (equipment). Dead space ventilation involves that component of the respiratory gases that does not participate in gas exchange. Simply said, there is no patient benefit from dead space ventilation. If mechanical dead space volume equals or exceeds alveolar ventilation volume the patient will not be able to clear carbon dioxide at all. Ideally, your goal should be to minimize dead space through proper patient planning and to detect excess dead space consequences through end-tidal CO₂ monitoring.

Anatomic dead space is comprised of the upper airway structures that do not participate in gas exchange. This includes the gases in the nasal passages, nasopharynx, larynx, trachea, and in the larger airways. **Alveolar dead space** represents those alveoli that are ventilated with fresh gas but not perfused by the pulmonary circulation. **Mechanical or equipment dead space** is made up of any portion of the endotracheal tube extending beyond the patient's incisors, patient monitor adaptors (ETCO₂, apnea alert, etc.), any adaptors used to facilitate patient/system positioning (right-angle or swivel adaptors used to reduce the risk of tracheal trauma during patient rotation), the space within a mask not occupied by the patient's nose, humidification management exchangers (HME), and the "Y" piece (defined as the terminal end of an F circuit or noncircle system and the inhalation/exhalation hose connector in a circle system).

Exhausted soda lime or malfunctioning one-way valves can also contribute to increasing mechanical dead space. Dead space also increases in a non-rebreathing system when fresh gas flows are inadequate or when certain defects are present in the system (for instance, when the center tube of a Bain system or F circuit is cracked or broken). These dead space contributors can all be controlled through proper system inspection and maintenance.

Mechanical dead space gas is the first gas inhaled at the beginning of the each respiratory cycle. As the mechanical dead space volume increases, *less* fresh gas moves into the patient's alveoli, limiting gas exchange.

Anesthetic System							
	Norman Elbow	Jackson-Rees	Bain	Ped circle	Adult circle	Adult F	Ped F
Dead space	<1 ml	3 ml	4 ml	4 ml	8 ml	8 ml	15 ml

Adaptors					
	ET tube	Monitor - ped	Monitor - adult	Positional	Heat & Moisture Exchanger (HME)
Dead Space	2 ml	2 ml	7 ml	8 ml	2.5 to 90 ml

The consequences of excessive mechanical dead space can be substantial and, potentially, fatal. As dead space volume from any cause increases, effective alveolar ventilation decreases. In patients breathing 100% oxygen there may be negligible initial effect on arterial oxygen tension. Arterial CO₂, however, can reach impressive levels. It is possible to have an end-tidal CO₂ level greater than 110 mmHg in patients with a normal pulse oximeter reading.

- Increased arterial CO₂ causes:
 - Respiratory acidosis
 - Sympathetic stimulation
 - Cardiac arrhythmias
 - A mix of sympathetic stimulation and hypoxemic effects
 - Variable peripheral vasoconstriction (sympathetic effect) followed by peripheral vasodilation as a direct effect on peripheral vessels
 - CNS depressant effect and, eventually narcosis
 - PaCO₂ levels above 100 mmHg have an anesthetic effect
 - Increased cerebral blood flow and intracranial pressure
 - Tachypnea and an increased work of breathing which can negatively impact a debilitated patient
- Arterial O₂ levels may eventually decrease enough to cause hypoxemia, especially in a patient breathing room air
- Inadequate ventilation interferes with adjustments in anesthetic levels

Controlling mechanical dead space is a simple matter.

- Mechanical dead space is most concerning for patients under 6 kg body weight
 - Minimize the connectors attached to the endotracheal tube, particularly in small patients.
 - For example, in a 6 kg patient under anesthesia the patient's alveolar ventilation volume would be 31.5 ml. Using a pediatric F circuit with adult ET CO₂ monitor and right angle adaptor (or apnea alert adaptor) could create 30 ml of mechanical dead space; effectively eliminating 95% of normal spontaneous alveolar ventilation.
- Make sure you regularly inspect all anesthetic machines and systems paying particular attention to valve function and inner hose integrity
- Make sure that the ET tube is not excessively long
- Select your anesthetic system carefully
 - Do **not** use a pediatric F circuit as a substitute for conventional pediatric circle hoses or a noncircle system
- Using no more than one monitor adaptor
 - Make sure it is a pediatric, low volume adaptor for smaller patients to avoid any significant impact on total mechanical dead space
- Avoid the use of positional (right angle) adaptors in smaller patients
- Avoid maintaining anesthesia with a facemask

Simply put, anesthetized patients should have their end-tidal CO₂ monitored for maximal patient safety.