Bio Vet Innovator Magazine
(Fueling The Future of Science…)
Volume 3 (Issue 9) SEPTEMBER 2026
OPEN ACCESS World Rabies Day – 28th September 2026 Popular Article

The Breathing Engine: How Diaphragm and Thoracic Muscles Work in Mammals and Birds

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DOI: https://doi.org/10.5281/zenodo.23013288

Received: September 26, 2026
Published: September 28, 2026

Abstract:

Breathing is the most fundamental rhythm of life. Every breath be the animal or human is dependent upon coordinated efforts between the diaphragm (the primary muscle of inspiration) and a network of thoracic muscles that build the shape of chest cavity. The mechanism of breathing varies as per different species specifically the variation and mechanism in breathing of birds and animals. This understanding of respiratory mechanism in both domestic mammals and birds help to reveal fascinating evolutionary adaptations among these species that further depict real clinical implications for the veterinarians.

Keywords: Breathing, Diaphragm, Evolutionary Adaptations, Thoracic muscles

The Mammalian Design: A Diaphragm-Driven Pump

In case of domestic mammals that include dogs, cats, horses, cattle and pigs, the diaphragm is the sole and main engine of breathing that serve as main muscle of inspiration. The diaphragm being dome-shaped musculo-tendinous thin membranous muscle completely partitions the thoracic cavity from the abdominal cavity (Brown et al., 1995). When the main inspiratory muscle contracts the flattening of dome shape takes place that further increases the thoracic volume. The increase in thoracic volume results in decrease of pressure (Boyle's Law) inside the thoracic cavity that result in entry of air into the lungs from the high pressure (atmospheric pressure) to the low pressure generated in thoracic cavity.

The Diaphragm's Regional Complexity:

The diaphragm is not only a uniform sheet of muscle instead it functions and serves as two distinct segments when researched in dogs: the **costal** and the **crural** portions. During quiet or normal breathing, there is intensive and earlier shortening of crural diaphragm than the costal portion of the diaphragm. This electrical activity result in the process of early expiration. The activity becomes more pronounced when the breathing is stimulated by increased level of CO_2, this differential behavior results in domination of the crural segment for early inspiration while the costal segment gets abrupt termination with airflow (Easton et al., 1993).

The mechanical properties of diaphragm vary regionally. In freshly excised dog diaphragms, the thickness near the chest wall and near the central tendon is nearly constant in the costal region, suggesting that muscle fibers either taper within bundles or exist in series with varying numbers along different perimeters (Péan et al., 1991). This architecture allows uniform stress distribution across the domed membrane (Péan et al., 1991).

Clinical Importance of the Main Inspiratory Muscle- the Diaphragm:

The study of main muscle of inspiration helps veterinarians to assess structure and function of diaphragm non-invasively using ultrasound. A study in dogs demonstrated that diaphragm thickness, change in thickness with respiration, and excursion amplitude can all be measured quantitatively (Sarwal et al., 2014). In dogs suffer with X-linked myotubular myopathy, have thinner diaphragm and was more echogenic than the wild-type dogs. The measurements became comparable to normal after gene replacement therapy (Sarwal et al., 2014). This technique provides an additional future alternative to invasive diaphragm assessment in both veterinary and human medicine (Sarwal et al., 2014).

The Thoracic Muscle Ensemble: (coordinated group of muscle working together as a single unit to produce a combined effect) -

While the diaphragm muscle maintains the main heavy lifting, the thoracic muscles aids fine-tune ventilation. The **Levator costarum** muscles—present from the second to the last rib in dogs, cats, and horses—elevate the ribs during inspiration (Frewein et al., 1987). In pigs, the location of these muscles extend from the second to the fifteenth rib (Frewein et al., 1987). The **Transversus thoracis** muscle actively determines end-expiratory volume in dogs. It provides contracting in phase with the expiration during quiet breathing (Brown et al., 1995).

In horses, respiratory muscles response different to training like any other muscle. The changes in respiratory muscle size have been measured ultrasonographically after exercise conditioning, and inspiratory muscle training has been investigated as a treatment for dynamic upper airway collapse in racehorses (Fitzharris et al., 2023a; Fitzharris et al., 2023b). This clinical observation recognizes the importance of breathing pump to strengthen the life of an animal (Fitzharris et al., 2023a).

The Avian Alternative: No Diaphragm, All Air Sacs

Birds in compare to mammals took a radically different and a unique evolutionary path. Birds lack a diaphragm entirely (Lightfoot, 2001). Instead, they ventilate their lungs using a system of nine air **sacs**—some positioned in front of the lungs (Cranially) and some behind (Caudally). These air sacs promote unidirectional and continuous flow of air during both inspiration and expiration thus act as bellows

Citation: Tamanna Agrawal, Lovish Sethi, Virendra Singh, Sanskar Gautam. (2026). The Breathing Engine: How Diaphragm and Thoracic Muscles Work in Mammals and Birds. In Bio Vet Innovator Magazine (Vol. 3, Issue 9, pp. 56–60). Bio Vet Innovator Magazine https://doi.org/10.5281/zenodo.23013288

(Maina, 2017).

The Advantage of Absence of Diaphragm in Birds:

In mammals, there has been reduction in efficiency of breathing of air due to its bidirectional flow. The air flows in and out of the alveoli tidally, thus mixing of fresh air with stale air (Maina, 2017). The unidirectional flow due to the absence of diaphragm and presence of air sacs in birds solved this problem. The lungs of birds contain parabronchi, (the structural and functional unit of respiration) which is a narrow tube that help in flow of air in one direction only (Maina, 2017). This cross-current gas exchange system remarkably increases the efficiency in birds by extracting more oxygen per breath than the mammalian tidal system (Maina, 2017).

The control of unidirectional flow maintained by aerodynamic valving (fluid dynamic forces) instead of anatomical valves or sphincters (Butler et al., 1988). During expiration, air from the caudal air sacs flows through the paleopulmonic parabronchi instead of bypassing the lungs, with valve efficacy reaching approximately 95% during exercise-level flow rates (Butler et al., 1988). Earlier modeling by Brackenbury (1979) corrected the Hazelhoff model of airflow in the avian lung, refining our understanding of this aerodynamic system (Brackenbury, 1979).

Consequences of the Avian Unique Design:

Since birds have no diaphragm to separate chest or the thoracic cavity from the abdomen, any predisposing factor that cause abdominal disease can directly impair breathing in birds (Lightfoot, 2001). A bird with an abdominal mass or fluid accumulation may show signs and symptoms like tail bobbing, open-mouth breathing, and increased respiratory rate. These signs occur not because of primary respiratory disease, but because of the mass that is compressing the air sacs which further disturbs the mechanism of breathing (Lightfoot, 2001).

There are interconnection and direct or indirect communication of avian respiratory system with the bones. A pneumatic bone if fractured bone can become a source of respiratory distress or infection for a bird (Lightfoot, 2001).

Why the Difference Matters?

For veterinarians, these anatomical differences are not academic. A dog in respiratory distress suffering from diaphragmatic paralysis requires a completely different diagnostic and therapeutic approach than a bird suffering with air sacculitis (Sarwal et al., 2014; Lightfoot, 2001). This is due to the dependency of birds on air sac movements to carry out their breathing mechanics and thoracic and abdominal coordination due to lack of diaphragm (Lightfoot, 2001).

In horses, at the time of exercise the respiratory system faces unique challenges. Saddle girth tension, upper airway collapse, and even swimming-induced apnea (where horses experience complete upper airway collapse during breath-hold) all are related with the muscular machinery of breathing

(Bowers et al., 2005; Jones et al., 2020). The horse's diaphragm has to generate enormous pressures during high-intensity exercise for its normal functioning, and research continues to explore how training and disease affect this capacity (Franklin et al., 2012).

Conclusion:

The diaphragm is a regionally specialized, ultrasound-accessible, trainable muscle that separates thorax from abdomen in mammalian breathing engine (Péan et al., 1991; Sarwal et al., 2014; Fitzharris et al., 2023a). Birds completely lack this mechanism, thus evolve an air sac system that promotes unidirectional airflow and superior gas exchange efficiency without any dependency on diaphragmatic muscle at all (Maina, 2017; Butler et al., 1988). These fundamental appreciating differences is important for those who care for domestic animals and birds, to recognize respiratory distress, clinical signs interpretation, and an appropriate care across species (Lightfoot, 2001).

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