

Comparative Histological Analysis of Pulmonary Vascular Structure in Pigeon Breeds: Evidence of Functional and Adaptive Respiratory Specialization

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Abstract:

Background:

The respiratory system of birds exhibits remarkable adaptations to meet the elevated metabolic requirements of flight. In this study, a comparative histological evaluation was conducted on the pulmonary parenchyma of three pigeon breeds: Tippler, Iraqi Red, and Fantail with particular focus on smooth muscle thickness and blood vessel diameters.

Aims:

The goal was to understand how vascular morphology adapts to the varying physiological demands associated with each breed's flight capabilities, providing further evidence that selective pressures related to behavior and lifestyle profoundly shape avian respiratory system. Sixty adult healthy pigeons were categorized, and samples of the lungs were obtained for histomorphometrical assessments.

Results:

The findings revealed $P < 0.05$ inter-breed differences reflecting functional specialization. Tippler pigeons, known for their prolonged flight endurance, presented with the thickest smooth muscle layers (47.89 μm) and the largest vascular diameters, suggesting a more advanced mechanism for regulating pulmonary hemodynamics and optimizing oxygen transport. Iraqi Red pigeons demonstrated intermediate structural features (37.95 μm), aligning with their moderate flight activity. In contrast, Fantail pigeons, which exhibit limited flight capacity, displayed the thinnest smooth muscle walls (33.96 μm) and the narrowest vessels, consistent with lower respiratory and metabolic demands.

Conclusions:

These observations underline the dynamic interplay between vascular morphology and physiological adaptation, providing further evidence that selective pressures related to behavior and lifestyle profoundly shape avian respiratory structures.

Keyword: pigeons, respiratory system, vascular.



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Introduction:

Birds, particularly pigeons, have a highly adapted and efficient respiratory system for flight (West, 2012). Pigeons, in comparison to their body size, have a small lung, but it is highly efficient for exchanging gases (Maina et al., 2002). Pigeons have special adaptations in the morphological and histological characteristics of the lower respiratory system. Pigeons have more compartmentalized air sacs (six) with a rigid and rudimentary syrinx than other avian species (Härtle et al., 2022). They have spongy lungs with a bright red color due to high vascularization, which allows for efficient gas exchange (Milsom and Burleson, 2007). One of the important factors for maximizing the oxygen exchange efficiency is the cross-current exchanging system that allows air to flow through the lungs in one direction with the perpendicular flow of the blood through capillaries (Moyes and Schulte, 2008). Pigeons' lungs have no alveoli like mammalian lungs; they have air capillaries that allow for gas exchange, and they are lined with a vascular respiratory membrane (Casteleyn et al., 2011). Lung tissue is made up of communicating bronchi and parabronchi and air capillaries to certify highly efficient gas exchange (Maina et al., 2002). High-flying pigeons like the Tipler have lung tissue with an adaptive characteristic that enables them to thrive in low-oxygen environments (Al-Agele, 2023; Al-Agele, 2024) and support their remarkable flying abilities (Michaeli and Pinshow, 2001). The aim of the current study is to investigate the physiological adaptations that allow high-flying pigeons to survive in such harsh circumstances. We look to understand the complicated relationship between oxygen availability and bird performance at altitude by studying their respiratory efficiency and the anatomical properties of their flight muscles.

Materials and Methods:

Sample Collection

Sixty healthy adult pigeons weighing about 250-311 g and aged 3-4 months were used for this study. The pigeons were divided into three groups: Tippler, Iraqi Red, and Fantail. These were purchased from the local bird market. Each group consists of twenty pigeons, ten for anatomical study and ten for histological study. The central portion was used to get the tissue samples after severing their jugular veins. We fixed the samples, processed them according to protocol, and stained them with H&E in accordance with the histological procedure. To prepare lung tissue specimens for microscopic analysis, the samples were initially cut and washed with a saline solution. They were then preserved by immersing them in a 10% formalin solution for 48 hours. The specimens then went through a dehydration procedure utilizing a sequence of graded ethanol concentrations for two hours each, progressing through 70%, 80%, 90%, and finally 100% ethanol. After dehydration, the samples were cleared with xylene for hours. Finally, the specimens were embedded in paraffin wax, allowing for the preparation of blocks from which serial sections, 5 micrometers thick, were cut using a microtome. The ribbon sections were stained after being placed on glass slides using hematoxylin and eosin (H&E) for enhanced visibility under light microscopy. These prepared slides were then inspected and captured on camera with a microscope equipped with a digital camera, ensuring high-quality imaging to get the measurements of the lung tissue; we use the sensitive balance to calculate the weight of the left and right lungs. Calibrated ImageJ software, which we then transferred to a Microsoft Excel sheet (Al-Agele 2023; Karim and Al-Agele 2024). An Olympus microscope equipped with an OMAX digital camera was used to photomicrograph histological sections.

Ethics approval:

This study was carried out following the strictest standards regarding the main rules of care and the use of animals in research. The experiment was conducted according to the guidelines of the College of Veterinary Medicine, University of Diyala Animal Experimentation Ethics Committee (No. VM 204, March 2024, Y&R), dated 3/5/20.

Results:

The lung of a domestic pigeon appears as a small organ covered by a fibroblastic connective tissue capsule. Trabeculae divide the lung parenchyma into numerous lobules, from which the bronchial tree and pulmonary blood veins branch. Every lung lobule originates from a central parabronchus surrounded by a dense air capillary network. The parabronchus is lined with simple,

column-shaped cells on top of delicate connective tissue, a layer called lamina propria, and thick, smooth muscle fibers. The lumen of the parabronchus opened into many funnel-shaped atria bordered by plain squamous epithelium. A dense network of air capillaries encircled the latter, joining the atria through infundibula. Flattened, attenuated simple squamous epithelial cells bordered the air capillaries. An extensive network of blood capillaries interacted with the air capillaries. The lamina propria revealed plenty of collagen fibers, which were mixed with the smooth muscle fibers of the main bronchus. But the density of the collagen fibers also dropped in the parabronchi wall of the atria and air capillaries. In the current study, a comparative analysis of smooth muscle thickness in the pulmonary parenchymal blood vessels of three pigeon breeds revealed notable differences. The Tippler pigeons exhibited the greatest smooth muscle thickness, averaging approximately 47.89 μm , suggesting a more robust vascular structure in this breed. In contrast, the Iraqi Red pigeons showed a moderate thickness of about 37.95 μm , while the Fantail pigeons demonstrated the thinnest smooth muscle layer, with an average measurement of 33.96 μm , as seen in Fig (1-2 and 4). These results indicate breed-specific variations in vascular muscle development, potentially linked to physiologic, flight-related, or environmental adaptation differences. The observed variations under light microscope, smooth muscle thickness among the three pigeon breeds suggest a correlation between vascular structure and potential physiological or functional demands. Tippler pigeons, which had the thickest smooth muscle (47.89 μm), may have a more developed pulmonary vascular system (main pulmonary artery) to help them get more oxygen during long flights or when they are more active. The moderate thickness in Iraqi Red pigeons (37.95 μm) and the relatively thin layer in Fantail pigeons (33.96 μm) might reflect lower demands on pulmonary circulation, potentially due to differences in flight endurance, body structure, or lifestyle. These findings highlight the influence of breed-specific traits on the microanatomy of the respiratory system and suggest that vascular smooth muscle development may be an adaptive feature linked to the functional needs of each breed.

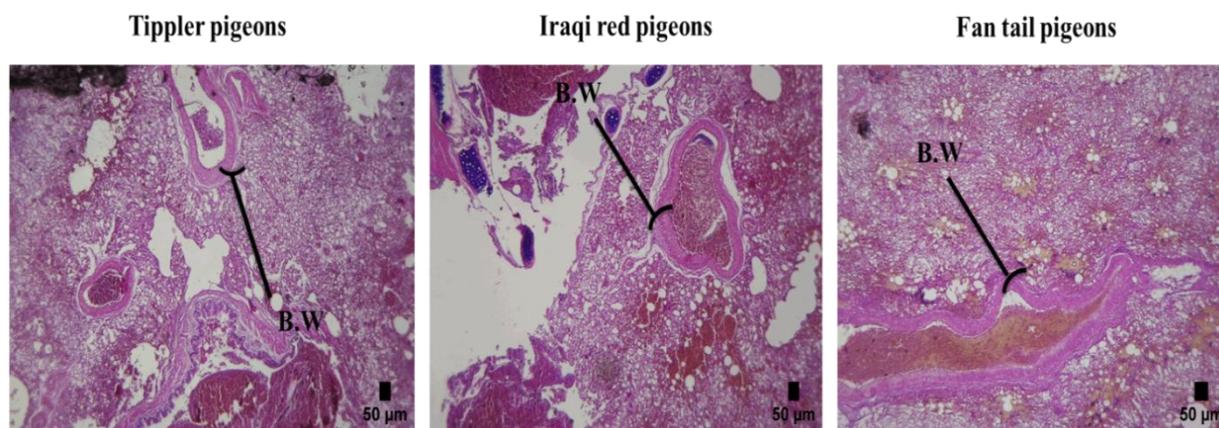


Figure (1): Photomicrographic images show the most significant variation in the thickness of the smooth muscle layer that surrounds the blood vessel (B.W.) walls that feed the lung tissue of pigeons at 50 µm.

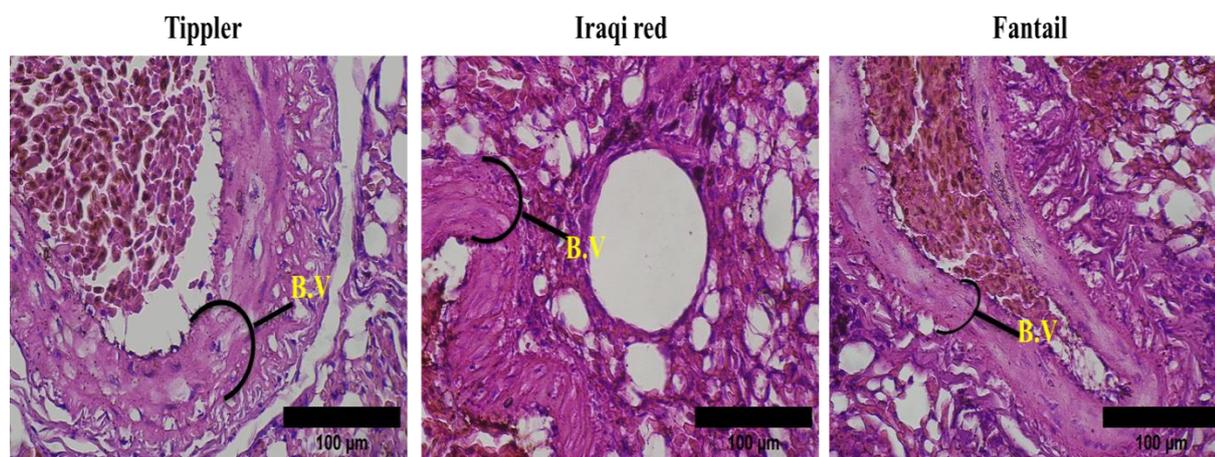


Figure (2): Photomicrographic images of pigeon lung tissue show the significant variation in the thickness of the smooth muscle layer that surrounds the blood vessel walls that feed the pigeons' lung tissue at 100 µm.

Comparison of Smooth Muscle Thickness in Pulmonary Vessels of Three Pigeon Breeds

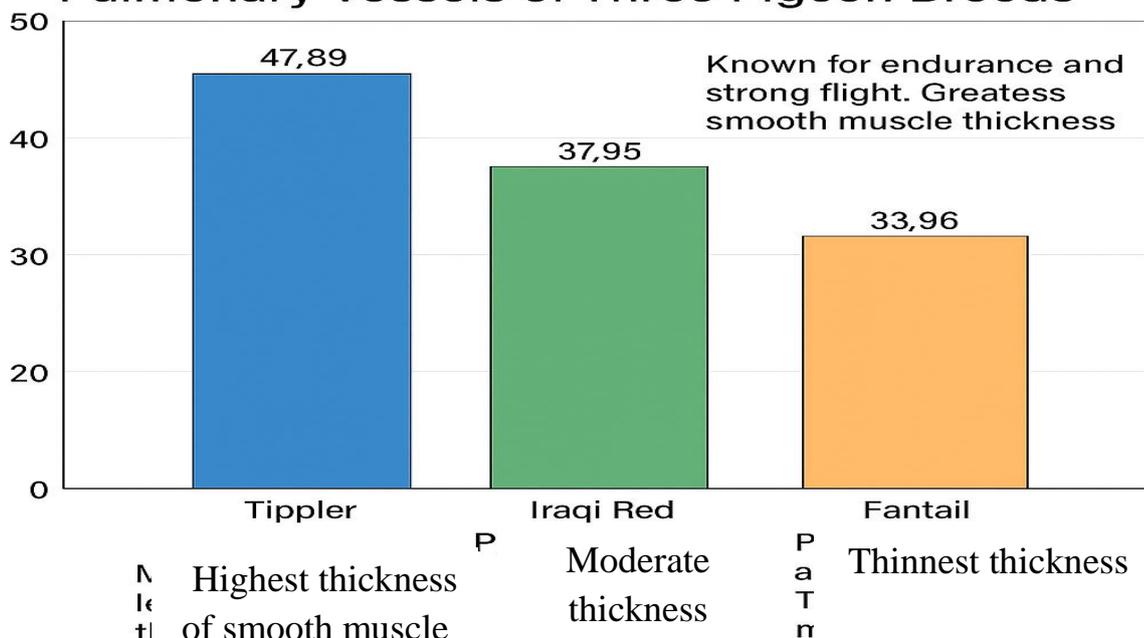


Figure (3): Graph illustrating three distinct types of pigeons: high-flying tippler pigeons, mid-flying red Iraqi pigeons, and low-flying fantail pigeons and their smooth muscle thickness values.

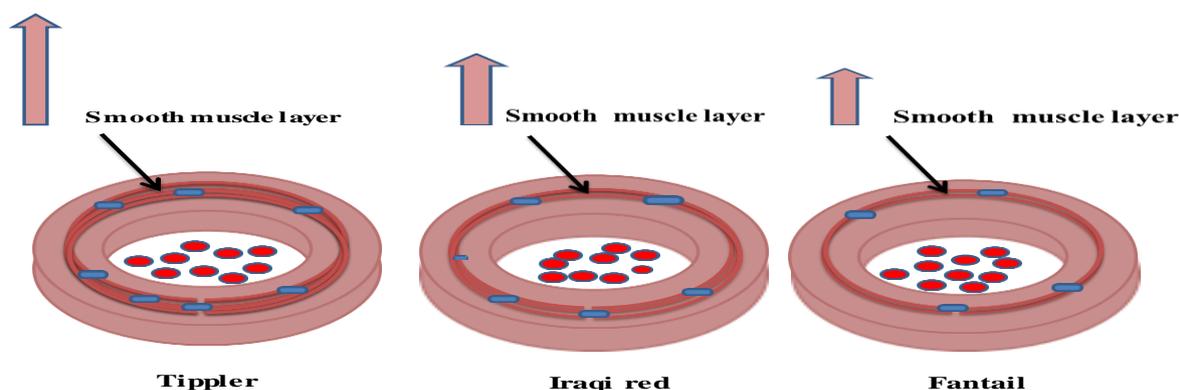


Figure (4): Schematic shows the differences in the muscular layer thickness between the compared pigeons.

The intricate network of air capillaries in pigeons and other birds increases oxygen intake and carbon dioxide removal by maximizing surface area and decreasing diffusion distance. Maintaining the high oxygen requirements linked to bird physiology depends on these structures. Histological examination

of air capillaries gives valuable information about the microstructural adaptations of the respiratory system and highlights possible breed-related variations in pulmonary function. The Tippler pigeons exhibited the highest mean air capillary diameter ($19.50 \pm 3.31 \mu\text{m}$), followed by the red Iraqi pigeons ($18.47 \pm 3.70 \mu\text{m}$). In contrast, the Fantail pigeons showed the smallest mean air capillary diameter ($11.20 \pm 3.29 \mu\text{m}$). These findings suggest breed-related differences in pulmonary microarchitecture, which may reflect functional adaptations or genetic influences.

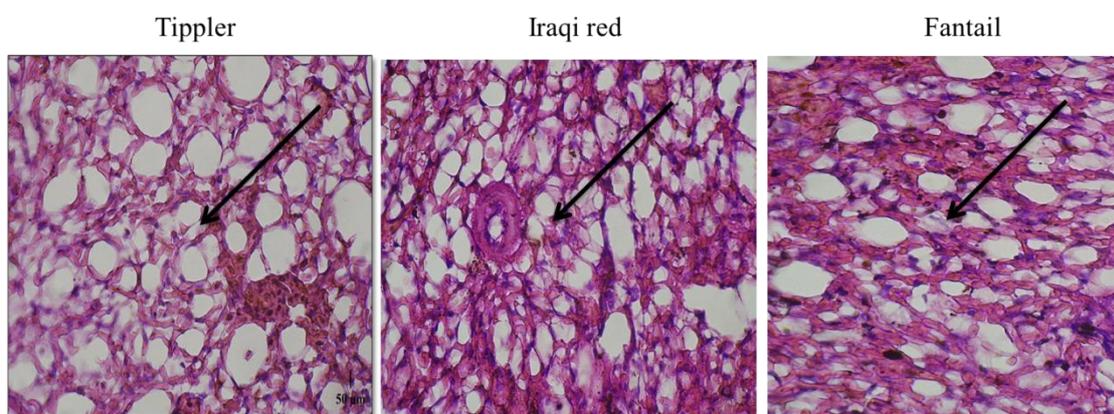


Figure (5): Photomicrographic images show the intricate network of air capillaries (black arrow) within the lung tissues of tippler pigeon. (H&E stain).

On the other hand, the glandular sacs within the parenchyma of the pigeon lung, which are specified structures essential for maintaining the health and function of the respiratory system by their glandular epithelium that secretes mucus and other protective substances, The comparative analysis of the diameters of sacs between three groups of pigeons revealed notable variances in their length and number. Tippler pigeons showed larger and more prominent glandular sacs ($54.81 \pm 3.02 \mu\text{m}$), suggesting a higher capacity for mucus secretion, possibly linked to their greater respiratory demands during prolonged flight. Iraqi Red pigeons showed moderately developed glandular sacs ($45.44 \pm 3.72 \mu\text{m}$), indicating a balanced function suited to their intermediate activity levels. In contrast, Fantail pigeons, which are less active and primarily ornamental, had smaller and less developed glandular sacs ($34.14 \pm 2.73 \mu\text{m}$), reflecting lower respiratory demands Fig (6). These findings imply that the physiological requirements and lifestyle of each breed are impacted by the size and development of glandular sacs, with more active pigeons needing stronger protective and supporting systems within their lung tissue Fig (6).

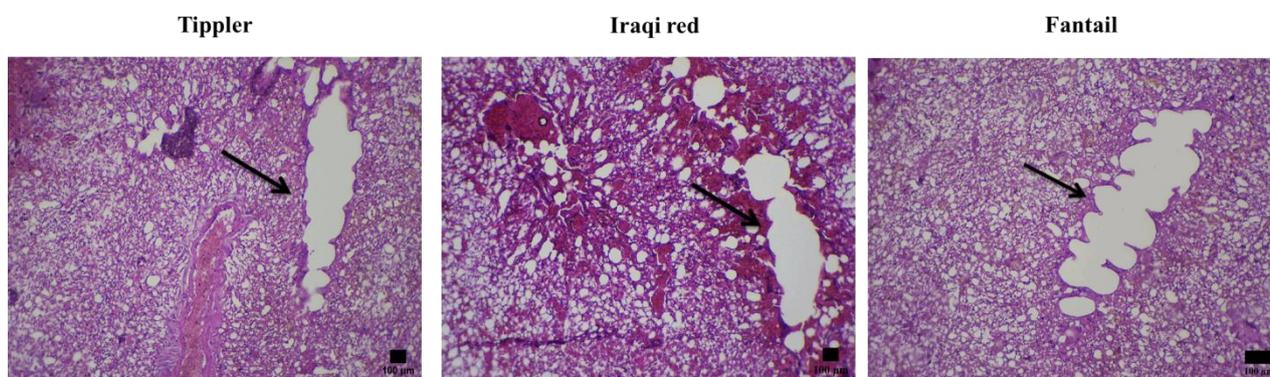


Figure (6): Photomicrographic images of pigeon's lungs show the significant variation in the diameters of the glandular sacs found within the parenchyma of the lung tissue of pigeons (100 µm, H&E stain).

Table (1): Histomorphometrical measurements of blood vessels, airways and glandular sacs in pigeons lungs tissues (µm).

Diameters	Tippler pigeons	Iraqi red pigeons	Fantail pigeons
Blood vessels	51.53 ± 2.87	21.40 ± 2.87	15.84 ± 2.94
Air capillaries	19.50 ± 3.31	18.47 ± 3.70	11.20 ± 3.29
Glandular sac	54.81 ± 3.02	45.44 ± 3.72	34.14 ± 2.73
Smooth muscle thickness	54.21 ± 3.29	33.29 ± 2.92	28.46 ± 4.40

Conclusions:

This study compares the lung tissue structures in different pigeon breeds, showing how their unique needs and ways of living have led to important changes. Tippler pigeons' lung tissue shows several physiological adaptations that contribute to their flight abilities and endurance capabilities. They have a thicker smooth muscle layer in their main pulmonary artery and a wider pulmonary arterial diameter, indicating they require better lung control for longer flights, which enhances the more functional specialization of hemodynamics and increases oxygen percentages and sufficient gas exchange at high altitudes. That's considered a hard environment due to the decrease in the partial oxygen pressure and low air pressure that affects the endurance capacity of flying birds. While Iraqi Red pigeons show average values that suggest they are moderate in the measured structures. Conversely, the reduced smooth muscle development and smaller vessel calibers in Fantail pigeons align with their limited respiratory demands. These findings emphasize the critical role of vascular remodeling in optimizing respiratory efficiency according to breed-specific behaviors, which provides important information about the relationship between structure and function within the avian respiratory system and adaptive respiratory specialization.

Recommendations:

Based on the findings of this study, we recommend the following:

- **Conduct further physiological studies:** To understand the precise mechanisms by which the observed histological differences contribute to pulmonary hemodynamic regulation and oxygen transport in each pigeon breed. This could include measurements of pulmonary blood flow, gas exchange efficiency, and respiratory responses during flight.
- **Expand the research to include other breeds:** To compare a wider range of avian breeds with varying flight capabilities and metabolic demands, enhancing our general understanding of the relationship between respiratory structure and function.
- **Investigate gene and protein expression:** To study the genes and proteins responsible for the development and maintenance of vascular smooth muscle and vessel size within the pulmonary tissue, which could reveal molecular mechanisms contributing to the observed adaptations.
- **Study the impact of environmental conditions and training:** On histological changes in the avian respiratory system to determine if these characteristics are genetically fixed or influenced by environment and exercise.
- **Apply these findings in breeding and husbandry:** This knowledge could contribute to selective breeding programs for pigeons, aiming to improve flight endurance or other specific traits relevant to athletic performance or commercial purposes.

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Conflict of Interest:

No conflicts of interest.

Funding Sources:

The funding sources is private

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