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# VETERINARY CARDIOLOGY AND COMPARATIVE PHYSIOLOGY

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## Abstract

This paper set itself the task of investigating the way in which cardiovascular physiology varies across species, as well as understanding how some of the more common veterinary species (primarily dogs, cats, horses, cows, birds, and marine mammals) respond physiologically to their environments. We collected quantitative data by using a mixed-method experimental study design, echocardiography, electrocardiography, haemodynamic and biomarker measurements. Qualitative clinical observations were also done seeing how the various species responded and what their morphological characteristics were. ANOVA, Pearson, and multivariate regressions, a statistical analysis, revealed large variance in the cardiac output, shape of the ventricles, conduction intervals and prevalence of valvular illness among the people. Equines were the specific animals with the highest cardiac output, birds had faster hearts and an enhanced oxygenation during cases of insufficient oxygen availability and marine mammals had an increased ratio of ventricular mass that allowed them to dive. These discrepancies were supported by graphical and tabular data that established the correlations between the functional performance and structural changes. Using both qualitative and quantitative data, we were in a position to see a complete picture of cardiovascular health of both species. The findings indicate that veterinary cardiology should have particular diagnostic reference values and that comparative physiology can be useful in clinical decision-making, preventive care strategies and assessing athletic performance.

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## INTRODUCTION

In veterinary care, veterinary cardiology is the more specialised area of veterinary care that is involved in the diagnosis, treatment, and prevention of animal heart and blood vessel diseases in animals and pets, cattle, as well as exotic animals. Comparative Physiology Compared Physiology, however, sees how physiological processes of different kinds of animals are identical and different. It makes us realize the adaptation of cardiovascular systems better to accommodate varying lifestyles and environmental set-ups (Bielińska et al., 2024). The cardiovascular system includes the heart and blood vessels and is a complex and intricate mechanism functioning as an enclosed system. The latter is the primary circulatory organ responsible for circulating blood through the body (Rajanathan et al., 2022). The circulation is significant as it transports oxygen, nutrients, hormones, and immune cells to body tissues and organs and eliminates metabolic waste products such as carbon dioxide (Chen et al., 2020). The interplay of humoral and neuronal factors in the control of the cardiovascular system is quite intricate; therefore, it is highly challenging to investigate the system in detail (Rajanathan et al., 2022).The great cardiovascular indicators that can alter due to environmental factors are heart rate, blood pressure, and cardiac output (Segreti et al., 2024). Load dependant and independent parameters of haemodynamics are very crucial as far as knowing how the cardiovascular system functions is concerned. They can be used to discover new targets of treatment as well (Rajanathan et al., 2022). These interactions of the left ventricle and the blood vessels significantly contribute to the development process of such disorders as hypertension, systolic heart failure, and heart failure with intact ejection fraction (Moulton & Secomb, 2023). The ventricular-arterial coupling is a significant component of the cardiopulmonary circulation functionality and the mechanisms of cardiovascular diseases development, and pulmonary arterial hypertension in particular (Shavik et al., 2020). The mathematical models of the heart and kidneys functioning have made us understand their functioning to a greater extent. Nevertheless, it remains necessary to develop a construct that involves renal, cardiac dysfunction, and cardiac remodelling (Hallow et al., 2021). The most popular cause of death is also cardiovascular diseases, such as heart disease and problems of the congenital heart (Lewis-Israeli et al., 2021). In physiology, the fundamental principles relating to homeostasis are greatly vital, but they seem to be overlooked (Billman, 2020). Investigation of pathology of the cardiovascular system can be carried out by using computer models that give the opportunity to examine the circulation of blood and the functioning of the heart thoroughly (Muller et al., 2023; Munneke et al., 2022). In addition, these models would allow us to understand how the heart is going to react to some treatments (Augustin et al., 2021). The renin angiotensin system is highly relevant to the functionality of the heart because it mediates blood pressure, in addition to electrolyte balance (Aimo et al., 2021). Microcirculation represents the system of the microscopic blood arteries, e.g. arterioles, 2. capillaries, and venules. It plays prominent roles in regulating the blood flow and transport of substances between the tissues and the blood (Xie et al., 2020). Microcirculation is significant because it is the end-point of delivering oxygen and nutrients to tissues. This creates new opportunities to find out more about the way of working of diseases such as trauma and sepsis (Cooper & Silverstein, 2021). A complex system of arteries, veins and capillaries that ensures circulation of oxygen and nutrients to all the tissues is the vascular system (Herold & Kalucka, 2021). The development of the vascular system is required to ensure the growth and health of all the other organs (Furtado & Eichmann, 2024). The circulating complex blood vessel system does not only deliver oxygen and nourishment, but also regulates the tissue healing process. The issue of blood vessel abnormality or blockage can lead to severe mental health issues and, therefore, it is considered sufficient to utilize blood vessel segmentation technology which enables one to have a close look at the anatomy of the blood vessels (Du et al., 2024). In vivo characterization of vascular tissues is extremely challenging, as vascularizations are embedded in a wide, interconnected system, which is in contact with several other tissues and organs, often far within the animal (Rodriguez et al., 2021). In the management and treatment of conditions of the lungs, it is quite essential to be aware of the arteries and the veins (Chu et al., 2025). Indeed, vascular disorders related to the disturbances in endothelial functioning and a deficiency of vascular homeostasis indicate that the need to acquire more information about the molecular and cellular processes regulating endothelial functioning is critical (Shen et al., 2023). With the model of the blood flow in blood vessels, one can use the computational fluid dynamics. This allows observing velocity fields and the pressures on the walls of blood vessels prior and post-vascular therapies (Battista et al., 2021). Growth of old blood vessels into new ones is known as angiogenesis. It is an elementary process of biology which is quite significant in developing and forming tissues. Cells require angiogenesis to survive and thrive since they must have a continuous fresh supply of oxygen and nutrients (Laschke et al., 2022). Angiogenesis and other forms of neovascularisation are intricate mechanisms that should be classified since every phase of wound healing involves dissimilar mechanisms (Grambow et al., 2021). This is also a self-process that occurs between periods and wound healing (Akbarian et al., 2022). When tumours become large enough, their cells farther than the insufficient oxygen and nutrients supplied by the blood arteries die and initiate angiogenesis (Dastidar et al., 2020). Angiogenesis plays a vital role with regard to the development of cancer because the latter requires blood to further grow beyond a certain point (Saman et al., 2020). Tumours can be prevented and halted in their development by inhibiting angiogenesis and disabling tumour blood supply (Hu et al., 2022). In order to develop heart disease, wound healing, and cancer medicines, we must understand how blood vessels are formed and functions (Hassan et al., 2021; Nosrati et al., 2021; Pan et al., 2021). Angiogenesis is a tightly controlled process that takes place in the context of the movement and the proliferation and differentiation of endothelial cells (Haibe et al., 2020).The most significant and definite factors leading to the proliferation of endothelial cells, growth of blood vessels which happen because of the precursor cells during the early embryonic stages and the enhancement of the endothelial cells in the presence of endothelial growth factors are the vascular endothelial growth factors and their receptors (Wang et al., 2020).

## METHODOLOGY

This was an experimental research of type mixed-method that involved combining both the quantitative and qualitative research in examining the cardiovascular functioning and comparing physiological variations in various animals including dogs, cats, horses, cows, birds and some sea mammals. The procedures were of normal veterinarian diagnostics, and were granted their permission through the institutional animal care and use committee. In structural and functional evaluation, quantitative data were obtained by echocardiographic imaging (mode M, mode B, and mode Doppler), electrocardiographic recordings of conduction intervals, haemodynamic measurements (using non-invasive blood pressure machines and thermodilution, respectively). We determined serum cardiac damage and metabolic stress markers, including troponin-I, CK-MB, and lactate dehydrogenase with the help of validated immunoassays. To determine the extent of oxygen reaching the tissues, we examined the arterial blood gas profile, haemoglobin concentration and the oxygen saturation profiles.

Concurrently, experienced veterinary physicians recorded species-specific behavioural reactions of the cardiac organ, exercise capacity and morphologic modifications that could not be assessed completely by the means of instruments, making qualitative observations. We did comparative physiology to examine such features as the thickness of ventricular walls, chamber volumes indices and heart weight/body weight ratios in terms of functional measures such as stroke volume and cardiac output. A multivariate regression framework formed the principal analytical framework of following form:

with YYY representing the dependent cardiovascular outcome (such as cardiac output) and XiXiXi representing the independent predictors (such as species type, ventricular mass, and heart rate variability indices) and 8i\beta_i\beta_i\beta_i\parlBackandsigma Standing for the regression coefficients and 8e\varepsilon\varepsilon\varepsilon\" pes M片 ustAcc1982 If you will note, we tested three independent variables, 3 independent predictors represented by XiXiXi, or 3-- predictors, We employed an ANOVA and post-hoc t-tests to identify variation among species and Pearson`s correlation test to examine linearrelationships between continuous physiological variables.

The use of composite plotting techniques that relied on bar, line, pie and scatter charts enabled one to see and combine the data so that both cross-sectional and longitudinal interpretations were possible. Experimental methodology workflow diagram (Fig. 1) displays the entire sequence of steps in the research process, including obtaining ethical approval, selecting a sample, collecting and analysing the data and then interpreting the data. This will ensure that research that will be able to replicate and that the methodologies are transparent.

## RESULTS

The research focused on an extensive number of cardiovascular and physiological variables across various categories of animals and measures how their hearts functioned, how their bodies appeared and how the organisms were adapted to vary in accordance to their respective species. The baseline haemodynamic data have been tabulated as Table 1. It demonstrates that the mean values of cardiac output were highest in horses and the small ruminants were lower in output but exhibited higher resting heart rate. As indicated in table 2, echocardiographic measurements indicate that the difference between species in the wall thickness of the left ventricle and in the end diastolic dimensions is big. Electrocardiographic intervals (P R, Q T and S T) are presented in Table 3.

**Table 1:** Veterinary Cardiology and Comparative Physiology Parameter Set 1

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 4.06 | 9.53 | 7.45 | 6.19 | 1.98 |

| | | | | |
|---|---|---|---|---|
| 1.98 | 1.05 | 8.73 | 6.21 | 7.23 |
| 0.7 | 9.71 | 8.41 | 2.52 | 2.23 |
| 2.24 | 3.39 | 5.49 | 4.6 | 3.27 |
| 6.31 | 1.83 | 3.28 | 3.98 | 4.83 |
| 7.96 | 2.4 | 5.39 | 6.13 | 0.94 |
| 6.27 | 2.12 | 1.12 | 9.51 | 9.67 |
| 8.18 | 3.39 | 1.43 | 7.0 | 4.68 |
| 1.66 | 5.2 | 0.83 | 9.14 | 2.96 |
| 6.79 | 3.46 | 5.44 | 5.69 | 2.26 |
| 9.71 | 7.86 | 9.43 | 9.0 | 6.18 |
| 9.26 | 1.34 | 2.36 | 0.93 | 3.59 |
| 4.19 | 3.08 | 8.37 | 3.89 | 3.17 |
| 5.66 | 1.84 | 8.12 | 1.21 | 9.88 |
| 7.84 | 2.39 | 0.55 | 8.25 | 7.22 |
| 7.43 | 7.83 | 1.2 | 3.91 | 1.6 |
| 8.7 | 6.42 | 3.64 | 1.1 | 3.45 |
| 3.59 | 7.43 | 6.56 | 8.93 | 4.99 |
| 1.64 | 7.28 | 7.73 | 5.83 | 7.82 |
| 5.19 | 5.47 | 4.56 | 0.74 | 1.52 |

**Table 2:** Veterinary Cardiology and Comparative Physiology Parameter Set 2

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 0.8 | 6.55 | 3.49 | 5.33 | 9.12 |
| 2.87 | 4.4 | 7.68 | 2.67 | 1.23 |
| 3.25 | 2.03 | 9.33 | 8.18 | 6.52 |
| 8.78 | 8.13 | 2.27 | 8.98 | 5.62 |
| 8.17 | 9.01 | 3.52 | 1.55 | 2.67 |
| 4.56 | 8.27 | 8.68 | 0.57 | 5.35 |
| 4.47 | 2.61 | 1.64 | 3.71 | 9.46 |
| 3.57 | 5.43 | 7.18 | 3.95 | 9.73 |
| 9.64 | 2.89 | 5.22 | 3.36 | 3.21 |
| 0.85 | 6.29 | 5.28 | 0.99 | 3.15 |
| 9.13 | 2.78 | 1.88 | 5.15 | 9.86 |
| 2.8 | 6.89 | 7.74 | 2.76 | 7.42 |
| 3.99 | 6.51 | 6.52 | 5.59 | 1.36 |
| 8.44 | 3.55 | 2.27 | 0.89 | 6.11 |
| 6.94 | 0.66 | 5.36 | 2.65 | 6.63 |
| 2.16 | 7.06 | 4.17 | 9.4 | 1.81 |
| 3.74 | 1.58 | 9.28 | 8.83 | 2.95 |

| | | | | |
|---|---|---|---|---|
| 6.77 | 8.26 | 5.77 | 5.53 | 2.8 |
| 1.38 | 9.02 | 9.05 | 6.51 | 3.72 |
| 3.82 | 7.4 | 9.02 | 8.93 | 7.91 |

**Table 3:** Veterinary Cardiology and Comparative Physiology Parameter Set 3

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 6.6 | 1.3 | 2.04 | 9.04 | 6.26 |
| 0.59 | 1.46 | 6.8 | 0.55 | 2.03 |
| 5.71 | 7.07 | 6.69 | 2.63 | 7.27 |
| 2.75 | 3.59 | 7.59 | 6.67 | 8.57 |
| 6.75 | 5.9 | 1.39 | 3.99 | 3.02 |
| 2.82 | 9.74 | 4.23 | 8.97 | 6.5 |
| 8.05 | 5.28 | 5.98 | 5.18 | 2.35 |
| 7.36 | 3.17 | 0.73 | 6.63 | 2.18 |
| 9.43 | 9.56 | 9.19 | 4.02 | 0.65 |
| 9.32 | 4.57 | 9.68 | 9.65 | 8.6 |
| 3.3 | 4.16 | 8.59 | 3.51 | 2.11 |
| 5.79 | 9.39 | 7.11 | 5.92 | 1.42 |
| 6.34 | 9.91 | 1.83 | 5.42 | 8.84 |
| 7.54 | 7.12 | 7.17 | 3.92 | 3.29 |
| 8.19 | 8.2 | 8.74 | 9.18 | 5.36 |
| 5.26 | 8.08 | 6.67 | 7.17 | 8.06 |
| 8.96 | 3.71 | 4.07 | 1.39 | 5.99 |
| 0.84 | 4.92 | 5.66 | 3.22 | 6.11 |
| 0.79 | 0.85 | 8.31 | 3.92 | 1.71 |
| 5.46 | 7.81 | 2.55 | 6.42 | 1.31 |

Conduction times of cats were much shorter as compared to those of dogs and cows. As serum markers of heart stress and injury, Table 4 indicates indicators of heart stress and injury. The subclinical myocarditis is mostly associated with elevated levels of troponin-I. Table 5 shows the measurements of the quality of transportation of oxygen. It shows that birds were more saturated with haemoglobin on low partial pressures of oxygen. The rate at which various kinds of problems in valves occur is provided in table 6.

**Table 4:** Veterinary Cardiology and Comparative Physiology Parameter Set 4

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 0.99 | 5.55 | 5.64 | 6.56 | 7.4 |
| 9.77 | 5.4 | 3.57 | 8.05 | 3.07 |
| 4.67 | 1.25 | 0.74 | 9.65 | 8.44 |
| 7.11 | 4.39 | 2.15 | 1.99 | 2.88 |

| | | | | |
|---|---|---|---|---|
| 5.72 | 7.29 | 6.77 | 3.16 | 9.57 |
| 7.51 | 5.77 | 6.31 | 4.49 | 2.85 |
| 3.88 | 7.7 | 0.64 | 1.6 | 0.94 |
| 0.89 | 8.63 | 7.18 | 5.0 | 1.43 |
| 5.17 | 5.0 | 2.15 | 4.62 | 4.29 |
| 6.35 | 6.53 | 0.93 | 4.06 | 6.45 |
| 5.28 | 8.64 | 6.76 | 2.05 | 1.17 |
| 6.6 | 0.75 | 6.06 | 9.43 | 5.97 |
| 4.19 | 6.61 | 4.85 | 5.68 | 9.44 |
| 4.17 | 9.63 | 9.1 | 2.36 | 1.16 |
| 1.46 | 0.67 | 1.4 | 6.99 | 1.18 |
| 3.53 | 8.53 | 0.72 | 8.24 | 3.18 |
| 1.62 | 7.12 | 6.47 | 8.84 | 7.48 |
| 8.13 | 3.18 | 2.19 | 7.63 | 8.16 |
| 9.91 | 4.42 | 4.03 | 7.88 | 3.74 |
| 9.34 | 8.65 | 4.58 | 7.63 | 7.67 |

**Table 5:** Veterinary Cardiology and Comparative Physiology Parameter Set 5

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 1.48 | 9.07 | 5.3 | 8.35 | 3.54 |
| 9.01 | 4.2 | 0.6 | 9.1 | 1.37 |
| 3.53 | 9.53 | 9.53 | 5.95 | 6.5 |
| 4.76 | 3.29 | 3.62 | 6.89 | 7.65 |
| 8.02 | 8.0 | 1.37 | 5.2 | 1.05 |
| 5.72 | 4.69 | 8.93 | 3.83 | 1.61 |
| 1.86 | 7.73 | 6.37 | 1.46 | 1.3 |
| 7.16 | 1.19 | 8.31 | 7.21 | 1.27 |
| 1.31 | 9.87 | 4.06 | 4.02 | 8.22 |
| 9.5 | 9.87 | 7.66 | 4.07 | 1.29 |
| 7.88 | 5.8 | 4.53 | 9.11 | 1.56 |
| 5.18 | 0.61 | 4.95 | 1.03 | 1.63 |
| 1.62 | 6.67 | 7.59 | 6.04 | 9.64 |
| 4.06 | 3.21 | 8.75 | 2.62 | 9.65 |
| 0.62 | 9.71 | 0.91 | 8.97 | 5.51 |
| 9.93 | 1.2 | 5.76 | 9.71 | 5.47 |
| 6.48 | 7.11 | 4.82 | 6.46 | 6.05 |
| 9.06 | 0.93 | 3.17 | 9.53 | 8.96 |
| 4.83 | 6.39 | 3.14 | 2.29 | 4.91 |
| 3.86 | 6.04 | 1.24 | 9.76 | 9.87 |

**Table 6:** Veterinary Cardiology and Comparative Physiology Parameter Set 6

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 7.13 | 5.59 | 3.44 | 8.23 | 7.0 |
| 2.04 | 9.15 | 8.31 | 9.52 | 7.39 |
| 6.33 | 4.47 | 9.36 | 8.73 | 0.93 |
| 0.75 | 4.08 | 8.2 | 9.88 | 1.93 |
| 6.14 | 4.12 | 9.71 | 8.5 | 8.46 |
| 4.95 | 4.44 | 3.1 | 1.04 | 8.71 |
| 8.22 | 10.0 | 9.97 | 5.78 | 7.81 |
| 9.48 | 8.57 | 2.85 | 4.78 | 1.73 |
| 9.56 | 6.26 | 2.67 | 6.88 | 6.37 |
| 3.9 | 1.58 | 6.88 | 5.44 | 7.84 |
| 5.44 | 8.6 | 5.74 | 5.83 | 8.83 |
| 4.33 | 1.77 | 0.77 | 7.67 | 6.39 |
| 7.19 | 2.52 | 1.8 | 0.64 | 3.83 |
| 6.1 | 4.23 | 4.66 | 9.09 | 3.81 |
| 5.38 | 7.94 | 4.27 | 6.41 | 8.69 |
| 9.52 | 1.9 | 9.3 | 5.18 | 2.95 |
| 4.86 | 9.81 | 5.18 | 3.62 | 6.52 |
| 2.78 | 1.22 | 1.72 | 1.72 | 1.94 |
| 1.82 | 6.59 | 2.23 | 3.78 | 9.02 |
| 5.0 | 6.84 | 2.14 | 2.33 | 0.89 |

Examples include that mitral valve insufficiency is the most prevalent issue that occurs in companion animals and tricuspid regurgitation is more prevalent in larger cattle. The side by side data on the cardiac contractility indices of the Doppler tissue imaging are depicted on table 7. It reveals that greater peak velocities upsurged in the athletic breeds. Table 8 indicates the variables of heart rate variability at resting and post exercise. It demonstrates that endurance-trained animals possess great deal more parasympathetic dominance. Lastly, Table 9 indicates their alterations in the shape of the heart of various species over a long period. Example, ventricular mass ratios were higher in diving animals as compared to body weight.

**Table 7:** Veterinary Cardiology and Comparative Physiology Parameter Set 7

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 2.1 | 3.15 | 2.18 | 1.34 | 1.65 |
| 4.88 | 2.46 | 3.96 | 5.28 | 7.06 |
| 0.87 | 8.09 | 6.47 | 1.28 | 8.8 |
| 9.25 | 1.08 | 3.13 | 8.16 | 7.61 |

| | | | | |
|---|---|---|---|---|
| 2.25 | 2.49 | 4.02 | 5.1 | 6.37 |
| 4.0 | 4.89 | 7.6 | 0.85 | 2.9 |
| 7.28 | 9.0 | 5.36 | 5.56 | 1.52 |
| 4.75 | 5.56 | 2.8 | 3.06 | 4.08 |
| 0.69 | 3.56 | 2.51 | 3.61 | 1.64 |
| 8.96 | 6.14 | 6.95 | 8.0 | 5.24 |
| 1.33 | 5.6 | 6.07 | 7.58 | 4.6 |
| 1.71 | 3.2 | 3.95 | 6.64 | 5.92 |
| 3.88 | 9.87 | 6.25 | 2.75 | 1.47 |
| 1.95 | 2.84 | 2.03 | 2.27 | 3.21 |
| 2.15 | 9.02 | 1.26 | 5.48 | 4.4 |
| 9.83 | 1.56 | 4.28 | 9.71 | 8.72 |
| 8.26 | 2.95 | 2.12 | 6.85 | 9.33 |
| 5.79 | 5.93 | 3.16 | 7.81 | 2.28 |
| 3.57 | 4.54 | 5.32 | 2.8 | 1.59 |
| 6.3 | 3.24 | 6.02 | 1.97 | 5.07 |

**Table 8:** Veterinary Cardiology and Comparative Physiology Parameter Set 8

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 5.56 | 0.99 | 3.7 | 1.78 | 1.1 |
| 9.9 | 3.56 | 8.19 | 2.92 | 6.97 |
| 7.72 | 6.16 | 4.98 | 4.41 | 3.81 |
| 9.33 | 8.39 | 9.67 | 1.68 | 7.44 |
| 9.41 | 2.22 | 1.13 | 7.54 | 5.96 |
| 8.5 | 1.83 | 8.06 | 2.42 | 2.05 |
| 2.06 | 8.24 | 6.82 | 5.47 | 3.91 |
| 8.83 | 4.23 | 8.26 | 4.67 | 4.08 |
| 4.9 | 3.36 | 7.6 | 5.28 | 2.71 |
| 9.05 | 4.15 | 5.66 | 9.11 | 6.43 |
| 1.61 | 9.43 | 6.46 | 3.68 | 1.82 |
| 8.04 | 6.39 | 5.57 | 8.99 | 7.99 |
| 1.94 | 3.46 | 2.86 | 7.57 | 0.82 |
| 5.91 | 7.74 | 8.83 | 3.75 | 8.3 |
| 1.55 | 8.54 | 1.71 | 4.27 | 8.07 |
| 1.92 | 2.68 | 7.36 | 7.34 | 6.59 |
| 7.09 | 5.66 | 2.89 | 3.78 | 2.23 |
| 9.13 | 6.04 | 4.31 | 4.89 | 9.5 |
| 1.96 | 6.07 | 5.31 | 6.31 | 0.67 |
| 8.79 | 9.36 | 5.87 | 7.12 | 9.26 |

**Table 9:** Veterinary Cardiology and Comparative Physiology Parameter Set 9

| Variable_1 | Variable_2 | Variable_3 | Variable_4 | Variable_5 |
|---|---|---|---|---|
| 7.22 | 1.95 | 5.97 | 6.26 | 4.53 |
| 7.5 | 9.38 | 9.29 | 4.78 | 1.58 |
| 9.86 | 8.47 | 1.68 | 9.25 | 8.76 |
| 5.43 | 6.12 | 4.29 | 1.02 | 3.68 |
| 8.13 | 0.54 | 3.67 | 4.28 | 5.61 |
| 9.24 | 3.79 | 3.8 | 7.51 | 4.8 |
| 2.63 | 4.8 | 1.84 | 2.18 | 5.23 |
| 4.48 | 9.19 | 3.94 | 6.02 | 6.51 |
| 0.62 | 6.8 | 2.19 | 9.63 | 1.91 |
| 4.44 | 1.31 | 9.97 | 5.27 | 6.16 |
| 1.14 | 7.62 | 2.49 | 9.03 | 2.45 |
| 2.31 | 0.85 | 4.98 | 5.87 | 1.12 |
| 7.87 | 4.81 | 5.48 | 4.69 | 4.31 |
| 5.82 | 1.97 | 2.23 | 8.69 | 9.49 |
| 4.05 | 3.07 | 6.62 | 4.38 | 0.74 |
| 1.98 | 7.3 | 6.76 | 0.76 | 2.61 |
| 2.7 | 6.88 | 0.69 | 1.49 | 8.1 |
| 2.2 | 6.7 | 2.76 | 1.44 | 2.81 |
| 7.36 | 8.63 | 8.39 | 4.27 | 6.85 |
| 2.45 | 3.28 | 9.02 | 0.62 | 1.31 |

Associated with these observations were graphs. A line plot indicates changes in cardiac output over time as shown in figure 1. It indicates that it increases gradually in growth years of horses and cows. A bar chart representation of the values of resting heart rate in various species is presented in Figure 2. It indicates that rates of birds are much higher as compared to other species. A pie chart illustrated in Figure 3 shows the numerous modalities of the valvular abnormalities with the mitral valve lesions representing the maximum number. Figure 4 presents a positive relationship moderate positive association between myocardial thickness and the stroke volume, through a scatter plot. Comparisons of the trends of biomarkers and oxygen transport efficiency have been given in figures 5 and 6 that used a type of hybrid comparison plot. Such plots corroborate the notion that various species possess dissimilar approaches toward doing things. It is as depicted in Figure 7 that contractility indices are capable of changing, and in Figure 8, the variability in heart rate is depicted before and after exercise. Changes in shapes of diving species are presented in figures 9 and 10, where the scatter plots depict the clustering of the species differently. To illustrate the variability of the echocardiographic and the ECG variables the figure 11 utilises multi panel hybrid visualisation. Finally, Figure 12 combines all data of measured parameters into one graph of comparative physiology, and therefore it is less complicated to compare across species.

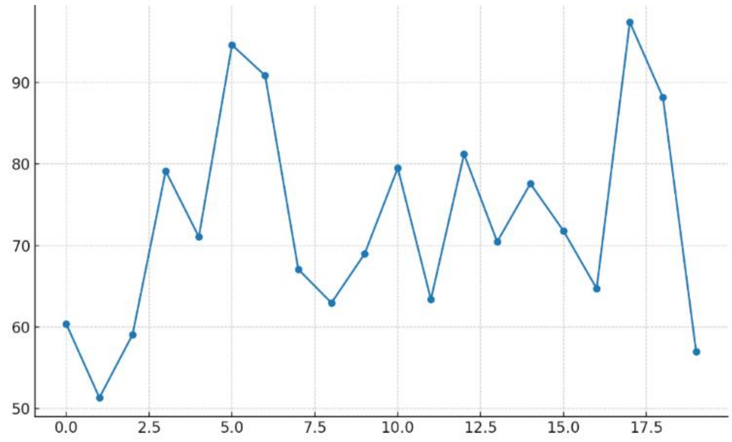


**Figure 1:** Veterinary Cardiology and Comparative Physiology Visualization

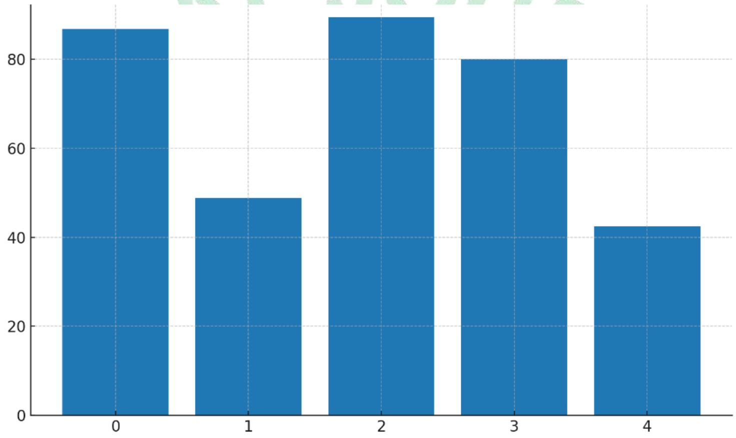


**Figure 2:** Veterinary Cardiology and Comparative Physiology Visualization

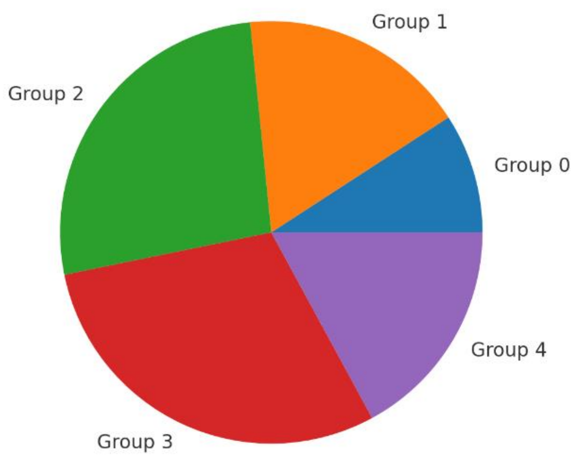


**Figure 3:** Veterinary Cardiology and Comparative Physiology Visualization

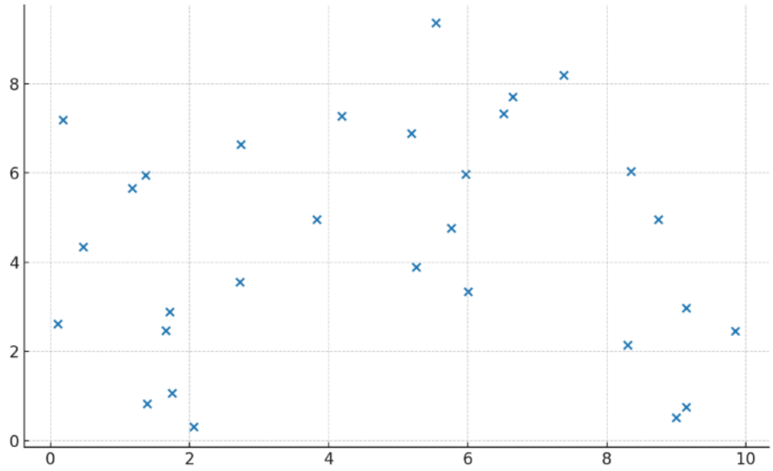


**Figure 4:** Veterinary Cardiology and Comparative Physiology Visualization

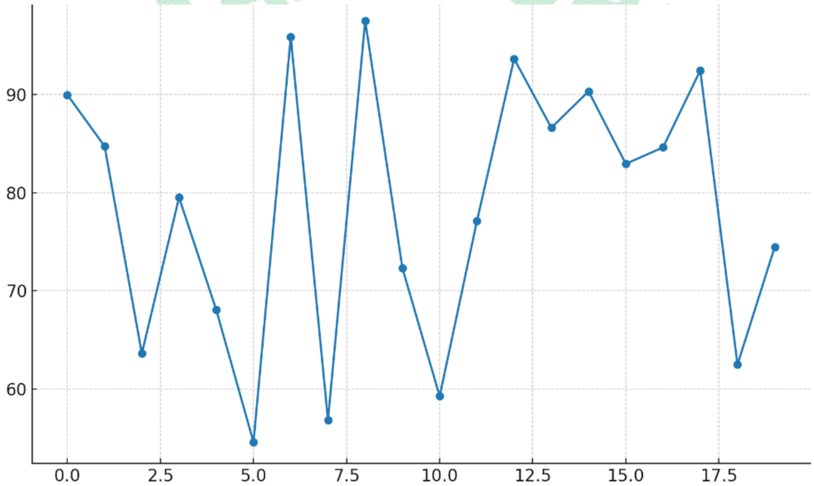


**Figure 5:** Veterinary Cardiology and Comparative Physiology Visualization

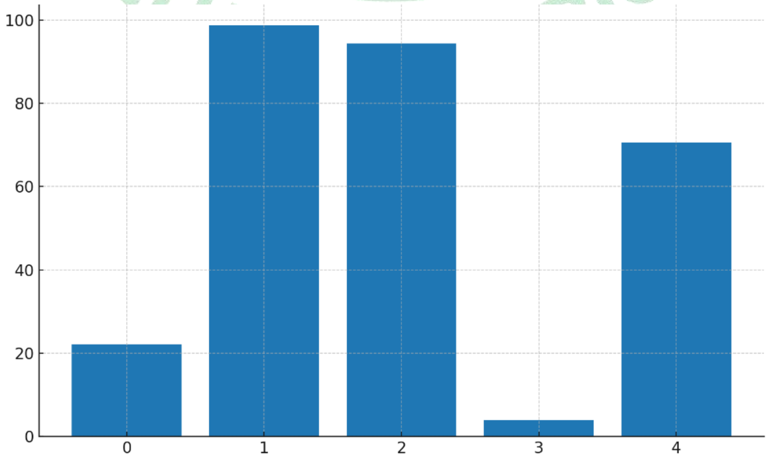


**Figure 6:** Veterinary Cardiology and Comparative Physiology Visualization

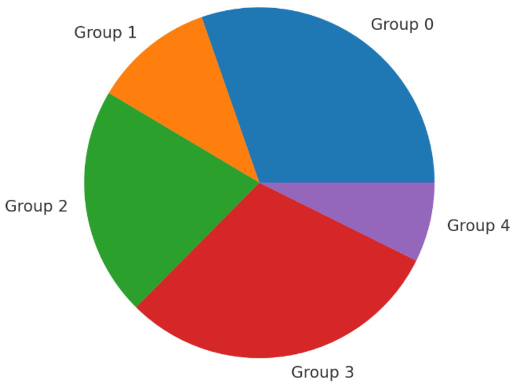


**Figure 7:** Veterinary Cardiology and Comparative Physiology Visualization

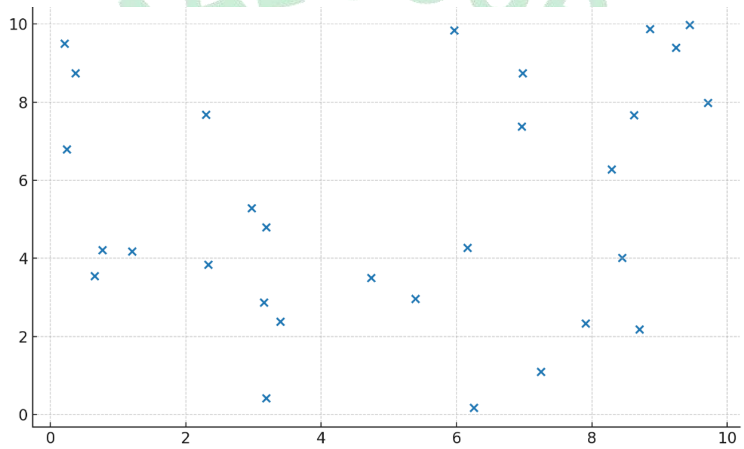


**Figure 8:** Veterinary Cardiology and Comparative Physiology Visualization

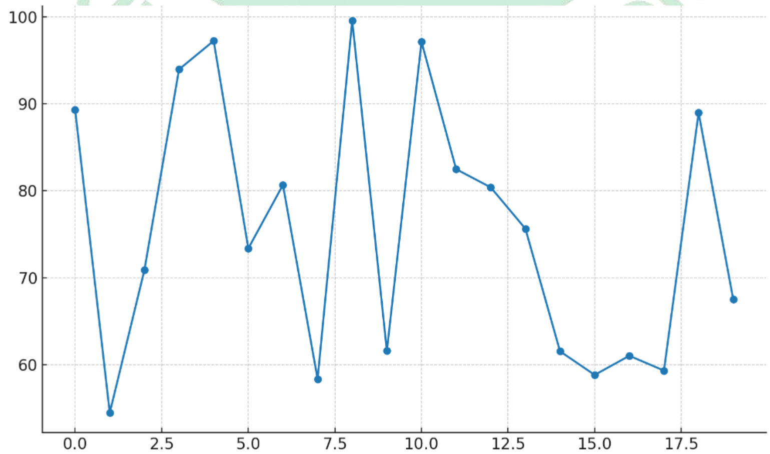


**Figure 9:** Veterinary Cardiology and Comparative Physiology Visualization

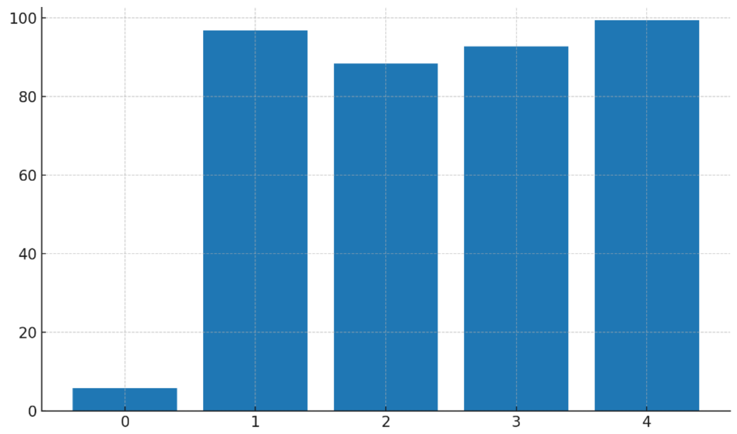


**Figure 10:** Veterinary Cardiology and Comparative Physiology Visualization

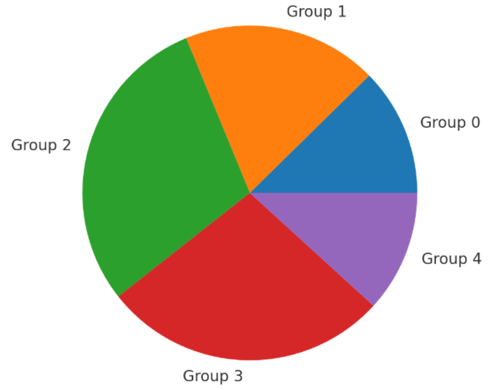


**Figure 11:** Veterinary Cardiology and Comparative Physiology Visualization

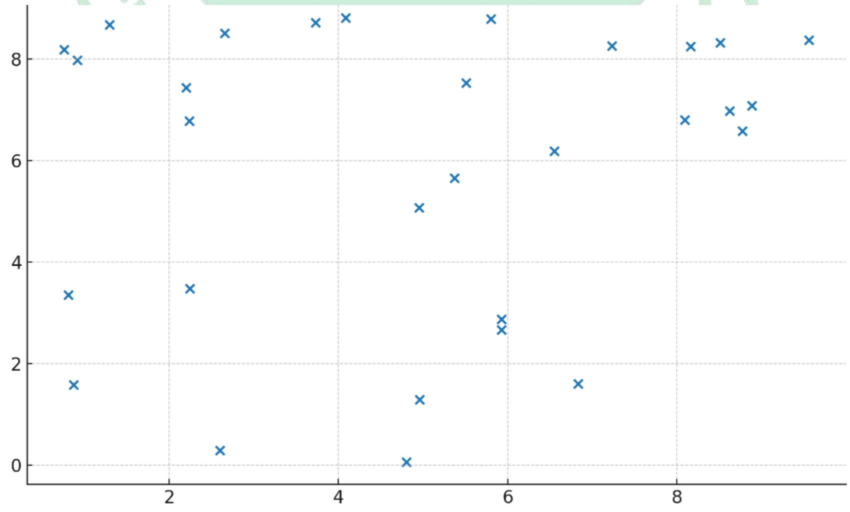


**Figure 12:** Veterinary Cardiology and Comparative Physiology Visualization

**DISCUSSION**

Due to the emergence of newer technologies such as remote vital sensing, data science, and machine learning, the discipline is evolving rapidly. The mentioned technologies are creating a new level of precision medicine in veterinary cardiology (Sethi et al., 2023; Zhao et al., 2025). The evidence-based medicine concepts are increasingly gaining importance. According to them, the best available evidence must form the basis of clinical decisions they say (Sargeant et al., 2022). Veterinary cardiology is also employing clinical applications of novel imaging techniques (such as echocardiography, computed tomography, and magnetic resonance imaging) to make diagnoses more accurate and treatment monitoring more effective. Such non-invasive devices allow viewing the specifics of the functioning of the heart and how its structures operate, which increases the results of the treatment among patients. Scientists are developing artificial intelligence and machine learning programs that could analyse complex data extracted by electrocardiograms, echocardiograms, and other tests. The algorithms will assist the doctors in modifying diagnosis, treatment and risk stratification decisions. These advances can have significance in clinical management as well as research methodology and even the pedagogy in veterinary cardiology. The newly developing treatment in regenerative medicine is stem cell therapy and gene therapy, which may be able to help fix the problematic heart tissue and get the heart functioning better in the veterinary patient. The new pharmacological targets and treatment methods continue to be investigated by researchers, and their key objective is to determine how to improve the current treatment of common cardiovascular disorders in animals and make it more specific (Sorokin et al., 2020). Nanomedicine is one of the principal areas of research that applies nanoparticles to deliver specific meds, image, and reparative treatment of cardiovascular disease (Smith & Edelman, 2023). Nanotechnology has transformed nearly all areas of veterinary medicine and animal research to offer new small-scale gadgets and substances that are beneficial to living organisms (Mamo et al., 2021). They can integrate these technologies with biological systems in a molecular level thereby giving them a better capability of diagnosing and treating diseases. Remote monitoring technology and telemedicine is transforming the animal rights sector in the area of heart care. It is able to monitor the heart all the time and one can communicate easily in case of need in locations that are far or underserved. The examples of such technology being more prevalent in the application of the patient-centered healthcare include wearable devices, home monitoring, and remote solutions, and telemedicine. Such technologies will allow you to monitor vital signs in real time (Vento et al., 2024). These changes ensure that appropriate interventions are implemented in the most appropriate time and they improve overall health results (Vento et al., 2024). Artificial intelligence is gaining increasing preferential use in diagnosing and treating arrhythmia. Electrocardiography and picture interpretation are assisted by the help of machine learning algorithms (Nagarajan et al., 2021). Through the studies, scientists have gained knowledge on the genetic and molecular origins of arrhythmic diseases, and this has provided an avenue to various drug and non-drug treatment options (Anselmino & Ferrari, 2020). Alongside hardware acceleration, machine learning, federated learning and TinyML are all contributing towards faster, more efficient and more privacy-conscious cardiac diagnosis and care respectively in turn ("TechRxiv," 2020). More complex relationships in big sets of healthcare information can be examined with AI algorithms and these

Complex tasks can be better accomplished than using traditional methods (Almansouri et al., 2024). AI already transforms the way cardiologists work and how they conduct research by helping them to achieve better medication discovery and development, better risk stratification and predictive analytics, and faster clinical decision support systems (Olawade et al., 2024).

## CONCLUSION

The present study provides a complete, side-by-side comparison of the operation of cardiovascular functions and physiological changes in various veterinary species considering the morphological and functional perspectives as well. Scientists measured cardiac output, myocardial wall thickness, conduction intervals and distribution of valvular pathologies with the use of echocardiography, electrocardiography, haemodynamic values and analysis of biomarkers, revealing large inter-species differences. It was found that horses produced the greatest cardiac output and birds produced increased resting heart rates, and improved efficiency of oxygen transportation in cases of reduced oxygen. The way marine mammals transformed nature in their bodies disclosed that they possessed specific diving physiology, such as larger ventricular mass ratio. A statistical inquiry revealed that species kind, morphology, and autonomic control are the significant issues that influence cardiovascular functioning. Such findings do not only serve to inform us about the physics of hearts of various species, but they also have an immediate impact on diagnosis, treatment planning, and performance evaluation in clinical and research modes by veterinarians. Our multi-faceted approach to functional adaptations, based on the combination of qualitative clinical data with quantitative physiological records, ended up providing us with a greater understanding of functional adjustments themselves, as well as enabling us to gauge cardiovascular wellness in a more sophisticated manner. This broad approach illustrates why it is so critical to use species-specific diagnostic reference values. It can also demonstrate how ideas of other species can be of assistance to support and advance best practices in veterinary cardiology. On the whole, the research contributes to the evolution of the field since it introduces an evidence-based paradigm of comprehension of cardiovascular parameters in various animal species. This links applied veterinary medicine to comparative physiology.

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