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Review

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The dog as an exercise science animal model: a review of physiological and hematological effects of exercise conditions

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[Purpose] Exercise is a fundamental way to maintain and improve health and physical fitness. Many human studies have demonstrated the beneficial effects of exercise on various biological parameters. However, studies investigating the effects of exercise in dogs are limited. This review summarized the current data from studies that examined the effects of different exercise conditions (treadmill vs. non-treadmill and acute vs. chronic) on physiological and hematological parameters in dogs.

[Methods] Papers addressing the effects of exercise in dogs published from January 2000 to October 2020 were retrieved from the online databases of Scopus, Google Scholar, and PubMed and were selected and reviewed.

[Results] The exercise conditions differentially affected physiological and hematological responses and adaptation in dogs. Therefore, the development and comprehensive evaluation of scientific exercise programs for dogs are necessary.

[Conclusion] The dog would be a valuable exercise science animal model, and studies aiming at the optimal health, well-being, and quality of life of dogs need to be conducted.

[Key words] exercise, physiological, hematological, animal model, dogs

INTRODUCTION

Humans and dogs are known to possess very similar anatomical structures and physiological mechanisms[1]. As companion animals, dogs also share the environment and lifestyle of humans. In dogs, obesity, diabetes mellitus, cancer, and cardiovascular diseases are associated with increased risks of disability, comorbidity, and mortality[2,3]. Most dog owners are well aware of the dangers of these disorders and strive to provide adequate health care and fitness management for their companions[3].

Exercise is a powerful intervention that induces significant outcomes in maintaining and promoting health and fitness. The treadmill, a well-known exercise system that provides controlled consistency in time, speed, and slope[4,5], is widely used in various research settings[6-8]. For example, Sessa et al. demonstrated that 10–12 weeks of treadmill exercise increased the vascular nitric oxide and the expression of its associated genes in dogs[9] whereas Lee et al. reported that only 4 weeks of exercise resulted in positive effects on physiological and hematological variables[10], suggesting that the efficacy of exercise varies according to conditions such as exercise frequency, intensity, type, and time (duration).

Many human studies have shown positive effects of exercise on health and fitness parameters[11-13]. However, studies investigating the effects of exercise in dogs under different exercise conditions are limited. This review aims to summarize the current data from studies examining the effects of treadmill and non-treadmill exercises on physiological and hematological parameters in dogs. Additionally, we reviewed studies investigating the effects of acute and chronic exercise in dogs. In this study, we consider the dog as an exercise science animal model and suggest a one health approach aiming at optimal health and well-being for humans and animals.

METHODS

A literature review was conducted using papers retrieved from databases including Scopus, Google Scholar, and PubMed. A combination of keywords, such as treadmill, underwater treadmill, exercise (voluntary, aerobic, endurance, interval), physical activity, training, hunting, hematology, heart rate (HR), and body temperature, was used to search the literature and the papers published from January 2000 to October 2020 were selected. Information from sources such as books, conference presentations, reports, and essays was excluded from this study.

RESULTS

The results of this review are presented in two parts. First, we summarized the results of physiological and hematological analyses of the treadmill and non-treadmill exercises in dogs (Tables 1 and 2). Second, we describe the results of studies that examined the effects of acute and chronic exercise in dogs (Tables 3 and 4).

Treadmill and non-treadmill exercises

Studies on treadmill exercises in dogs focused on walking, trotting, and running continuously or with intervals [11,12,14-15] (Table 1). Piccione et al. analyzed the physiological and hemodynamic parameters in seven healthy male beagles using sequential exercises: walking (3.8 km/h, 10 min), trotting (7.2 km/h, 20 min), and walking (3.8 km/h, 10 min) on a motorized treadmill. The results indicated that the HR and rectal temperature significantly increased with walking and trotting exercises. Red blood cell (RBC), hematocrit (Hct), lactate, and glucose levels increased only with the trotting exercise. These results can be partly explained by the fact that, cardiovascular parameters such as HR, blood pressure, and cardiac output increase to meet cellular oxygen requirements during exercise in dogs, like in humans[16]. The body also continues to produce and utilize adenosine triphosphate, an energy currency, through chemical reactions involving various substrates (i.e., glucose, fatty acid, and lactate) to meet the energy demands[17].

In line with this study, Queiroz et al.[14] examined the effects of treadmill walking and running exercises on HR and blood pressure in healthy military dogs. Their exercise program lasted for a total 12 min, consisting of three batches: 3.2 km/h, 0°, 4 min; 6.4 km/h, 0°, 4 min; and, 6.4 km/h, 10°, 4 min. The dogs were divided into three groups according to age. The post-exercise diastolic arterial pressure increased significantly in older dogs than in younger dogs[14]. Therefore, this study showed that the response to the treadmill exercises differed by age; this observation demonstrates that older dogs are more prone to physical fatigue than younger dogs due to a reduction in their cardiovascular and physiological functions[14].

Recently, Lee et al.[12] developed a scientific exercise program applying the frequency, intensity, time/duration, type, volume, and progression (FITT-VP) principles and examined its effect on physiological, hematological, and serum parameters. Four healthy, 2-year-old male beagles underwent continuous and interval treadmill exercises. These two types of exercise programs did not show any adverse effects

Table 1. Summary of treadmill exercise studies in dogs

Study	Animals and participants	Method	Measures	Results
Piccione et al., 2012	Healthy male beagles, 4–6 years old, n=7	Treadmill	HR Rectal temperature Hematological and serum chemistry	Significantly increased lactate, glucose, RBC, and Hct levels in the trot section were observed. Significantly increased HR and rectal temperature in walk and trot sections were observed.
Radin et al., 2015	Six males and eight females, Border Collies, 3.9 years old, n=14	Treadmill	HR deflection point	The HR deflection point was confirmed through the submaximal graded exercise test
Queiroz et al., 2016	Healthy military dogs, 2–8 years old, n=9	Treadmill	HR Blood pressure Thermographic image analysis	Despite the increased exercise intensity, the HRs of the groups did not differ significantly. Significant changes in blood pressure were identified in all the groups according to changes in exercise intensity. In group 1, the temperature of the biceps muscle increased significantly.
Rizzo et al., 2017	Seven male and three female mixed-breed dogs, 1–4 years old, n=10	Treadmill	Body and rectal temperature Hematological and serum chemistry	Exercise increased the temperature of the dog's neck, shoulder, ribs, flank, and legs. Significant changes in RBC, Hb, and Hct levels were identified.
Lee et al., 2020	Healthy male Beagles, 2 years old, n=4	Treadmill	HR Hematological and serum chemistry	The early HR reactions to the continuous and interval exercises showed irregular patterns, but the patterns regularized corresponding to changes in motor intensity. The CK and cholesterol levels of the dogs that performed the exercise changed significantly.

HR, heart rate; RBC, red blood cell; Hb, hemoglobin; Hct, hematocrit; CK, creatine kinase.

Table 2. Summary of non-treadmill exercise studies in dogs

Study	Animals and participants	Method	Measures	Results
Rovira et al., 2007	Six male and nine female healthy mixed-breed dogs, 1.5–11.5 years old, n=15	Agility exercises	Hematological and serum chemistry ELISA	RBC, Hb, Hct, and TG levels significantly increased after the agility exercises; moreover, the lactate levels exceeded the threshold of 4 mmol/L.
Pasquini et al., 2010	Five male and four female Italian hounds, 2–5 years old, n=9	Continuous walking and trotting	Oxidative stress indices	Significant changes in active oxygen and antioxidant defense levels were identified according to exercise type and recovery time.
LECA et al., 2017	Three males and two females, Golden Retrievers, 1.5–3 years old, n=5	Free exercise of a playing type	HR Lactate	The average HR during the exercise was approximately 60 % of the HR_{max}, and lactic acid levels showed no significant difference.
Santos et al., 2017	Seven male and three female beagles, 2–4 years old, n=10	Whole-body vibration	Hematological and serum chemistry	Significant changes in RBC and MCV were noted after exercise.
Colussi et al., 2018	Healthy mixed sexes, English Setters, Griffon Nivernais, Border Collie, Labrador Retriever etc., <1 year old, n=27	Pointing, Tracking for ungulate hunting, Blood tracking, Agility training, Animal-assisted activities	Cortisol	Cortisol levels increased significantly after pointing and animal-assisted activities.

ELISA, enzyme-linked immunosorbent assay; HR, heart rate; RBC, red blood cell; HGB, hemoglobin concentration; Hct, hematocrit; TG, triglycerides; MCV, mean cell volume.

on hematological and serum variables. In contrast, these exercises induced significant differences in creatine kinase and cholesterol levels. The HRs observed in the early exercise protocols (protocols 1–6) showed irregular patterns; however, in the latter protocols (protocols 7–12), the HRs showed regular patterns according to changes in exercise intensity[12]. Since dogs are easily distracted at low treadmill speeds and HR is sensitive to surrounding conditions[18], these results are meaningful. They suggested an exercise guideline that induces adequate and regular HR responses.

Several studies have investigated the effects of various forms of non-treadmill exercise in dogs[16,19-22] (Table 2). Colussi et al.[22] analyzed the cortisol response according to five different physical activities (pointing, tracking for ungulate hunting, blood tracking, agility training, and animal-assisted activity) in outdoor play. Cortisol, a primary stress hormone released following the activation of the hypothalamic–pituitary–adrenal axis, is sensitive to physical activity and the environment[22]. The authors found that cortisol levels significantly increased with pointing and animal-assisted activity. Because pointing is a type of endurance exercise that requires long-lasting and robust stamina, cortisol levels are believed to have increased due to the physical activity and negative energy balance[23]. In contrast, animal-assisted activities do not require high fitness levels. Nevertheless, much psychological preparation is required as it involves the performance of new types of physical activity. This study indicates that physical, psychological, and environmental factors related to exercise in dogs affect physiological and hematological parameters; therefore, exercise programs need to be comprehensively developed and evaluated.

Long-duration or exhaustive exercise can produce excess reactive oxygen species that exceed the limits safely manageable by antioxidant defenses, consequently leading to oxidative stress[24]. However, repeated endurance exercises reduce the oxidative stress in dogs[25]. Pasquini et al.[19] investigated the effects of two outdoor aerobic exercises (i.e., 20-min vs. 4-h duration) on oxidative stress and recovery time in trained dogs. After each aerobic exercise session consisting of walking, trotting, or non-stop running for food search, the derivatives of reactive oxygen metabolites significantly decreased 3 days after the exercise. In addition, the biological antioxidant potential increased 1 day after the exercise. The recovery time was shorter in the 4-hour exercise group than that in the 20-min exercise group[19]. These findings suggest that monitoring the oxidative stress and antioxidant force might be useful to establish ideal exercise adaptation in dogs.

Vibrating platforms, machines that cause vibrations that are indirectly transmitted through the legs to the whole body, are used for sports training and rehabilitation[26]. Whole-body vibration exercise effects are influenced by the type of vibrating platform, vibration amplitude and frequency, number of sessions and duration, and body position[27,28]. To obtain physiological and hematological data for whole-body vibration exercise in dogs, Prisby et al.[29] used 10 healthy beagles that exercised for 15 min/day over 5 days. Although the exercise significantly reduced the dogs' RBCs and mean corpuscular volumes (MCV), these parameters remained within the reference range. Because whole-body vibration exercise in dogs positively affects rehabilitation and sports training and does not cause any side effects[29], we would expect to see exciting results, supporting the need for further research.

In the study by Rovira et al.[16], agility exercises were performed by 15 dogs in a 400-m-sized field with 40 obstacles installed to assess fitness levels and motor skills. The agility exercises significantly increased RBC, hemoglobin, and triglyceride levels in the blood. In addition, Hct, an indicator of oxygen transport capacity in muscles, increased with exercise[16]. This study suggests that systemic short-term agility exercises can positively affect hematological variables in dogs.

Acute and chronic exercise

Many studies have analyzed various health parameters according to exercise duration (acute and regular) in humans and animals[30,31]. In general, acute exercise was defined as lasting for up to 4 weeks[32], and chronic exercise was defined as that lasting for 8 weeks or longer[33]. Tables 3[10,34-36] and 4[37-39] show the changes in the physiological and hematological parameters according to acute and chronic exercise in dogs.

In a study by Lee and his colleagues[10], old and young dogs carried out endurance exercises of different intensities at 70% of HR_{max} for older dogs and 50% of HR_{max} for younger dogs for 4 weeks (Table 3). The HRs during exercise and recovery time after exercise were significantly higher in older dogs than those in younger dogs. Moreover, exercise induced significant changes in the white blood cell counts and alkaline phosphatase levels in older and younger dogs, respectively, which are favorable due to their effects on immunity and bone metabolism[10].

McKenzie et al.[34] examined the effect of short-term long-distance endurance racing on serum biochemical variables in dogs. Consistent with findings from a study in humans[40], the study showed that creatine kinase and aspartate transaminase levels significantly increased with exercise, which is believed to be a result of musculoskeletal damage[40].

Davenport et al.[35] examined the effects of high-intensity hunting exercises on serum biochemical variables and found significant changes in MCV, phosphorus, and chloride levels. Similar results were found in a study by Angle et al.[36], which included 18 healthy mixed-breed sled dogs. All dogs ran 3 miles at an average speed of 24.3 km/h, and the average total workout time was 12.2 min. High-intensity racing exercises significantly influenced the sodium, chloride, albumin, calcium, and cortisol levels in dogs. The decrease in albumin associated with water loss is thought to be an immediate response to sustained high-intensity exercise[36]. However, no dogs exhibited exercise-induced dehydration in the study, and the intracellular phosphorus and extracellular chloride transfers that occurred because of respiratory alkalosis were involved in the changes[41].

While many studies have reported the effects of exercise in humans, limited studies have analyzed the impact of chronic exercise on physiological and imaging aspects in dogs. In a study by Lee et al.[37], six healthy male beagles underwent an interval exercise consisting of 12 protocols over 12 weeks. One beagle had a mean HR of 181.2 beats per minute ± 1.4 during the exercise, which was significantly higher than that in the other beagles (mean HR during exercise: 155.1 beats per minute ± 0.9) (Table 4). In this study, thoracic radiography, cardiac ultrasonography, and Holter electrocardiography tests were conducted to assess the dog's heart disease because abnormal HR responses during exercise can increase the risks of arrhythmia, heart failure, and ventricular fibrillation[42]. However, hematological and serum chemistry and imaging analyses for medical examinations confirmed the absence of atypical findings. The study data may help to establish a reference range for HR response in dogs after an interval exercise.

Vrbanac et al.[39] analyzed biomarkers related to bone metabolism (bone alkaline phosphatase, c-telopeptide of type I collagen, osteocalcin) following low-intensity treadmill exercise three times a week, 25 min/time, for 16 weeks. They reported no differences in the levels of bone metabolism biomarkers. In contrast, 12 weeks of combined dietary restrictions and incremental treadmill exercise (water and ground) led to positive weight loss and body composition in obese dogs[38]. These results suggest that an adequate intensity of exercise and its incremental increase are essential factors determining the physiological and hematological effects of long-term exercise in dogs.

Table 3. Summary of acute exercise studies in dogs

Study	Animals and participants	Method	Duration	Measures	Results
Davenport et al., 2001	Eight male and fifteen female dogs, 1.1–11 years old, n=23	Quail-hunting	2 weeks	Body weight BCS Hematological and serum chemistry	Significant changes were noted in the levels of MCV, serum phosphorus, and chloride during the quail-hunting season, and somewhat different results were observed in each group depending on the feed.
McKenzie et al., 2007	Six male and four female Alaskan sled dogs, 2–7.4 years old, n=10	Endurance racing	5 days	Serum chemistry	The levels of calcium, creatine, ALP, and ALT in dogs that performed endurance racing changed significantly.
Angle et al., 2009	Healthy mixed breed sled dogs, 2–8 years old, n=18	High-intensity racing exercise	1 day	Hematological and serum chemistry	High-intensity racing exercises significantly changed sodium, chloride, albumin, calcium, and cortisol levels in dogs.
Lee et al., 2019	Health mixed-sex beagles, 1-10 years old, n=11	Treadmill	4 weeks	HR Hematological and serum chemistry	Older dogs were found to have significantly higher resting HRs, HR during exercise, and HR recovery time when stable compared to younger dogs.

HR, heart rate; BCS, body condition score; MCV, mean corpuscular volume; ALP, alkaline phosphatase; ALT, alanine aminotransferase.

Table 4. Summary of chronic exercise studies in dogs

Study	Animals and participants	Method	Duration	Measures	Results
Vitger et al., 2016	Overweight, sedentary dogs, mixed breed, 2–13 years old, n=19	Treadmill	12 weeks	BCS Body composition Hematological and serum chemistry DAX	Positive effects on weight and BCS were identified in obese dogs that performed treadmill exercises.
Lee et al., 2019	Healthy male beagles, 2 years old, n=6	Treadmill Holter monitoring Digital radiography Echocardiography	12 weeks	HR Hematological and serum chemistry Cardiovascular disease	The HR of one beagle that performed the interval exercise was significantly higher than that of the control group, but the imaging analysis showed no abnormal findings.
Vrbanac et al., 2020	Healthy both sexes, >2 years old, Labrador Retriever, Golden Retriever, n=20	Treadmill	16 weeks	BALP CTX OC	The 16-week moderate exercise did not significantly affect the dogs' bone resorption.

HR, heart rate; BALP, bone-specific alkaline phosphatase; CTX, c-telopeptide of type I collagen; OC, osteocalcin; BCS, body condition score; DAX, fan-beam dual-energy x-ray absorptiometry.

CONCLUSION

In conclusion, exercise conditions differentially affect physiological and hematological responses and adaptation in dogs. Exercise programs for dogs should thus be designed with an emphasis on these results. Considering that studies in dogs are conducted by applying a scientific exercise program based on the FITT-VP principle that is applicable to humans, a strong exercise program for dogs needs to be developed and evaluated comprehensively. Exercise science research is lacking in dogs as compared to humans and rodents; however, it is an area that warrants active study. This would contribute to improving the health, well-being, and quality of life of dogs[23].

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