

Physiological Effects of Water Temperatures in Swimming Toy Breed Dogs^[1]

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Summary

The purpose of the present study was to examine the effect of water temperature on heart rate and respiratory rate during swimming, as well as changes in rectal temperature, blood glucose and blood lactate before and after swimming. Twenty-one small breed dogs (male = 9, female = 12) were used as subjects of this study. Dogs swam for 20 min in different water temperatures: 25°C, 33°C and 37°C. Heart rate and respiratory rate were monitored every 5 min during swimming. Blood samples were obtained before and after swimming for analysis of glucose and lactate levels. Rectal temperature was measured before and after swimming. The results showed that dogs that swam in 25°C water had the highest heart rate and serum glucose level (significant difference, $P<0.05$). The highest respiration rate was found in dogs that swam in 37°C water ($P<0.05$). Serum lactate significantly ($P<0.05$) increased after 20 min swimming at all water temperatures. Thus, the dogs should swim in 33°C water to prevent tachycardia, hyperventilation and hyperthermia.

Keywords: Dog, Heart rate, Lactate, Respiration rate, Water temperature, Swimming

Su Sıcaklığının Yüzdürülen Küçük Cüsseli Köpeklerdeki Fizyolojik Etkileri

Özet

Bu çalışmanın amacı su sıcaklığının yüzmeye öncesi ve sonrası kalp atım ve solunum sayılarına, rektal sıcaklığa, kan glikoz ve laktat seviyelerine olan etkisini araştırmaktır. Yirmi bir küçük cüsseli köpek (erkek=9, dişi=12) bu çalışmada denek olarak kullanıldı. Köpekler 20 dakika farklı ısılardaki suda (25°C, 33°C ve 37°C) yüzdürüldü. Kalp atım ve solunum sayıları yüzmeye süresince 5 dakikada bir ölçüldü. Glikoz ve laktat ölçümleri için yüzmeye öncesi ve sonrasında kan örnekleri alındı. Rektal sıcaklık yüzmeye öncesi ve sonrası ölçüldü. Sonuçlar 25°C'de yüzdürülen köpeklerde kalp atım sayısı ve serum glikoz seviyesinin en yüksek olduğunu ortaya koydu ($P<0.05$). En yüksek solunum sayısı 37°C suda yüzdürülen köpeklerde tespit edildi ($P<0.05$). Serum laktat seviyesi 20 dakika yüzmeye sonrasında tüm su sıcaklıklarında anlamlı derecede artma gösterdi ($P<0.05$). Sonuç olarak köpekler taşikardinin, hiperventilasyonun ve hipertermiinin engellenmesi amacıyla 33°C suda yüzdürülmelidir.

Anahtar sözcükler: Köpek, Kalp atım sayısı, Laktat, Solunum sayısı, Su sıcaklığı, Yüzme

INTRODUCTION

Swimming is one of the most popular exercises, and has many therapeutic benefits as well. It can increase muscle strength and endurance, and improve cardiovascular system function. Swimming exercise increases blood flow, resulting in increased oxygen supply to the muscles and

a higher rate of release of waste products from muscles into the bloodstream^[1]. Moreover, exercising in water can be beneficial by minimizing weight-bearing forces, thus reducing pain and allowing improved range of joint motion and muscle strength^[2,3]. The therapeutic properties



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of water include buoyancy, resistance, and hydrostatic pressure.

However, swimming in a pool also can result in some complications. Nganvongpanit and Yano [4] reported on the side effects in 412 dogs (male = 219 and female = 193) from swimming in a chlorinated swimming pool; these included dry hair (20.63%), dry skin (18.93%), and abrasion wounds at the armpit (15.78%), all of which increased with greater frequency of swimming. Other adverse effects were red eye (13.59%), otitis (6.31%), and a small number of respiratory problems (0.49%).

The functional and metabolic responses to swimming are influenced by duration, intensity, frequency, and environmental conditions. Water temperature during swimming is one of the most important factors involved in these physiological changes. Previous studies have proven that water possesses higher specific heat and thermal conductivity than air, by approximately 25-fold [1,5]. Hence, exercise in water places a much more severe thermal load on the body compared to exercise in air [6-8].

Many researchers have studied the effects of water temperature in animal models and in humans [1,9-16]. Those reports found that low water temperature close to body temperature resulted in longer exercise compared to higher water temperature close to body temperature and very low temperature (lower than 20°C), respectively. However, as yet there have been no reports on the effect of water temperature on physiological changes in dogs during swimming. Swimming for the exercise and rehabilitation of dogs has become of increasing interest in the field of veterinary medicine; however there is still only a limited amount of basic data. For this reason, this study has investigated the effects of water temperature on some physiological changes in dogs during swimming, including heart rate, respiratory rate, blood glucose and lactic acid.

MATERIAL and METHODS

Animals

Twenty-one small breed dogs (male = 9, female = 12) including Poodle (n = 1), Chihuahua (n = 15) and Pomeranian (n = 5) served as subjects in this study. All animals were healthy, age 55.6±12.05 months, weight 3.10±1.01 kg. The dogs were examined by a veterinarian through a physical examination, blood evaluation (cell count and blood chemistry) and analysis of radiographic images of the heart and lungs. The experimental protocol was approved (2012) by the Faculty of Veterinary Medicine and the Ethics Committee, Chiang Mai University, Thailand.

Experimental Design

All animals were trained to swim on at least 5 or 6 occasions prior to the start of the experiment, in order to

prevent overly excited behavior during swimming which could affect the results [17]. During the experiment, dogs were allowed to swim 20 min for collection of data [17]. This study used a mobile whirlpool (V.S. Engineering, Bangkok, Thailand). Three different water temperatures were used in this study: 37±2°C, 33±2°C and 25±2°C. All dogs are swam in three different temperatures 1 week interval.

Data Collection

Physiological data - including heart rate, respiratory rate, body temperature, blood glucose, and blood lactic acid - were measured. Heart rate during the experiment was recorded real time using a pulse watch (CHF-100-1VDR; Casio, Tokyo, Japan), while respiration rate was monitored by two veterinarians using counting machine (SDI 1055, Thailand). Rectal temperature was detected using a rectal thermometer. Two ml of blood was collected from the cephalic vein two times, pre- and post-swimming; these samples were used to evaluate glucose and lactic acid levels. Blood glucose was measured using blood glucose electrodes (Optium Xceed, MediSense®; Abbott Diabetes Care, Doncaster, Australia). Blood lactate was analyzed using an automated high-throughput system (DiaSys Diagnostic Systems, Holzheim, Germany) at a diagnostic laboratory at Maharaj Nakorn Chiang Mai Hospital, Faculty of Veterinary Medicine, Chiang Mai University, Thailand.

Statistical Analysis

The heart and respiration rates of subjects were measured at 5 min intervals, from pre-swimming (0 min) to the end of the testing period (20 min). This data, as well as rectal temperature and levels of blood lactate and glucose pre- and post-swimming, are presented as means. Relative changes of rectal temperature, blood lactate and glucose pre- and post-swimming were also calculated to compare between the three groups. Differences in mean values between two or more experimental groups were tested using ANOVA, followed by multiple pairwise comparisons using a *t*-test. Differences of $P < 0.05$ were considered to be significant. All data were analyzed using SPSS version 17.0.1 software.

RESULTS

Heart rate increased during 20 min of swimming in all three water temperatures (Fig. 1). However, heart rate in water temperature of 25°C showed a significantly higher increase ($P < 0.05$) compared to the other two temperatures (33 and 37°C), beginning after 5 min of swimming and continuing through the end of the testing period (20 min). After 20 min, the heart rate of dogs swimming in 33°C water was significantly higher ($P < 0.05$) than that of dogs swimming in 37°C water.

Respiration rate increased during 20 min of swimming only in dogs swimming in a water temperature of 37°C

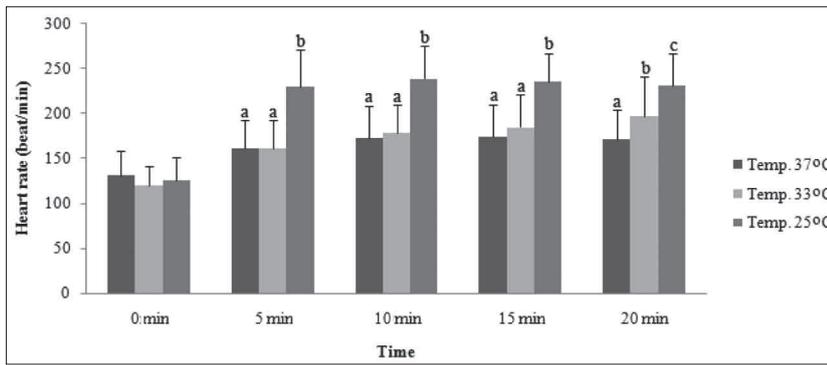


Fig 1. Mean (\pm SD) change in heart rate during swimming in different water temperatures. Individual bars show the mean \pm SD. Significant differences ($P < 0.05$) between the three temperatures at the same time are indicated by superscripts (a,b,c) above the bars

Şekil 1. Değişik sıcaklıklardaki suda yüzme sırasında kalp atım sayısının ortalama (\pm Standart sapma) değişimi. Bağımsız sütunlar ortalama \pm standart sapmayı göstermektedir. Aynı zamanda üç sıcaklık için anlamlı derecedeki farklar ($P < 0.05$) sütunların üzerinde üst simge olarak (a,b,c) belirtilmiştir

Fig 2. Mean (\pm SD) respiration rate change during the experiment in different water temperatures. Individual bars show the mean \pm SD. Significant differences ($P < 0.05$) between the three temperatures at the same time are indicated by superscripts (a,b) above the bars

Şekil 2. Değişik sıcaklıklardaki suda yüzme sırasında solunum sayısının ortalama (\pm Standart sapma) değişimi. Bağımsız sütunlar ortalama \pm standart sapmayı göstermektedir. Aynı zamanda üç sıcaklık için anlamlı derecedeki farklar ($P < 0.05$) sütunların üzerinde üst simge olarak (a,b) belirtilmiştir

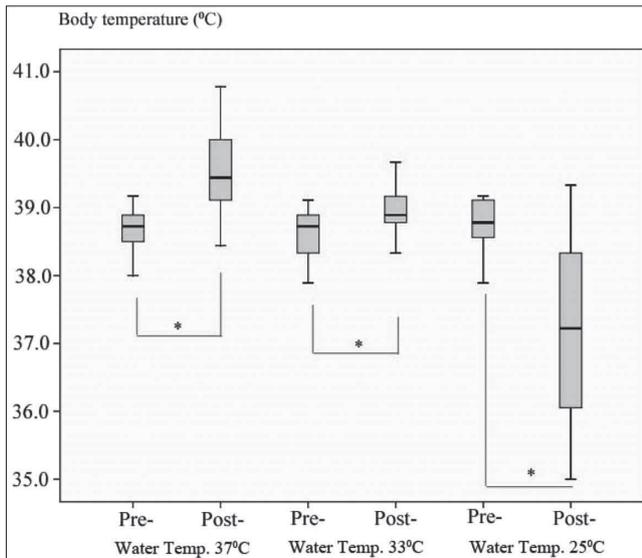
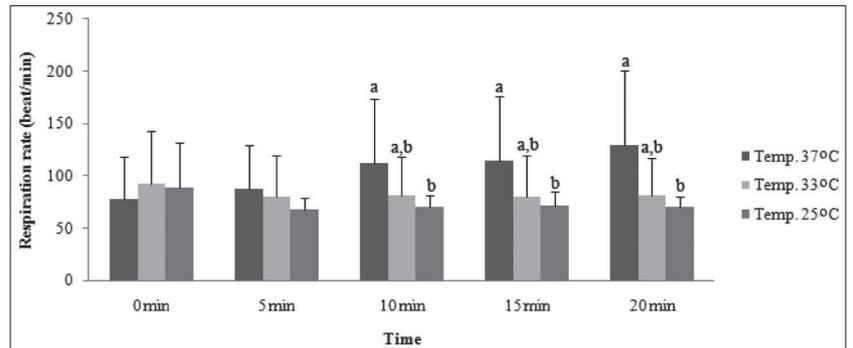


Fig 3. Comparative body temperature between pre- and post-swimming in different water temperatures. A significant difference ($P < 0.05$) was found between pre- and post-swimming at the same water temperature (*)

Şekil 3. Değişik sıcaklıklardaki suda yüzme öncesi ve sonrası orantısız vücut sıcaklıkları. Aynı sıcaklıktaki suda (*) yüzme öncesi ve sonrası anlamlı derecede fark ($P < 0.05$) tespit edildi

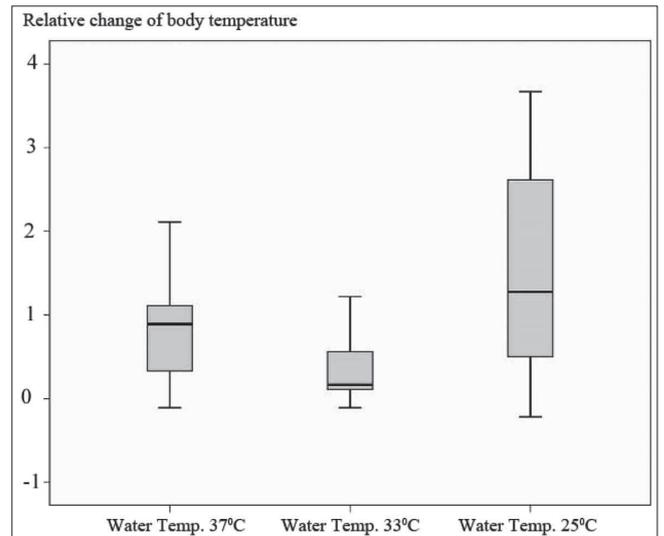


Fig 4. Relative change of body temperature in dogs swimming in different water temperatures

Şekil 4. Değişik sıcaklıklardaki suda yüzen köpeklerde orantısız vücut sıcaklığı değişimi

(Fig. 2). When dogs swam in water temperatures of 33 and 25°C, their respiration rate decreased. The respiration rate of dogs swimming in 25°C water was significantly lower ($P < 0.05$) than that of dogs swimming in 37°C water after 10, 15 and 20 min of swimming.

Body temperature after swimming was significantly different ($P < 0.05$) compared to pre-swimming (Fig. 3).

After swimming in 37°C water, body temperature increased from $38.68 \pm 0.32^\circ\text{C}$ to $39.54 \pm 0.63^\circ\text{C}$. After swimming in 33°C water, body temperature increased from $38.59 \pm 0.38^\circ\text{C}$ to $38.92 \pm 0.47^\circ\text{C}$. Conversely, swimming in 25°C water resulted in a decrease in body temperature, from $38.74 \pm 0.34^\circ\text{C}$ to $37.22 \pm 1.27^\circ\text{C}$. However, the relative changes of body temperature after swimming in all water temperatures were not significantly different (Fig. 4): 0.86 ± 0.63 , 0.33 ± 0.47 and 1.52 ± 1.22 in water temperatures of 37, 33 and 25°C, respectively.

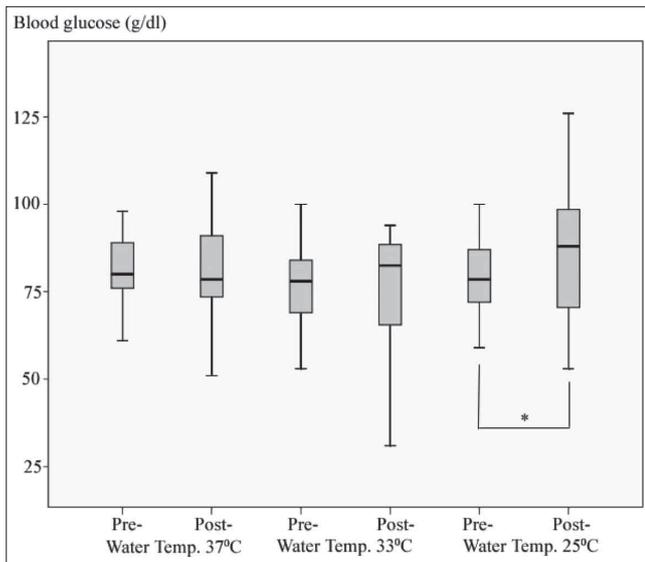


Fig 5. Comparative blood glucose levels between pre- and post-swimming in different water temperatures. A significant difference ($P<0.05$) was found between pre- and post-swimming at the same water temperature (*)

Şekil 5. Değişik sıcaklıklardaki suda yüzmeye öncesi ve sonrası orantısız kan glikoz seviyeleri. Aynı sıcaklıktaki suda (*) yüzmeye öncesi ve sonrası anlamlı derecede fark ($P<0.05$) tespit edildi

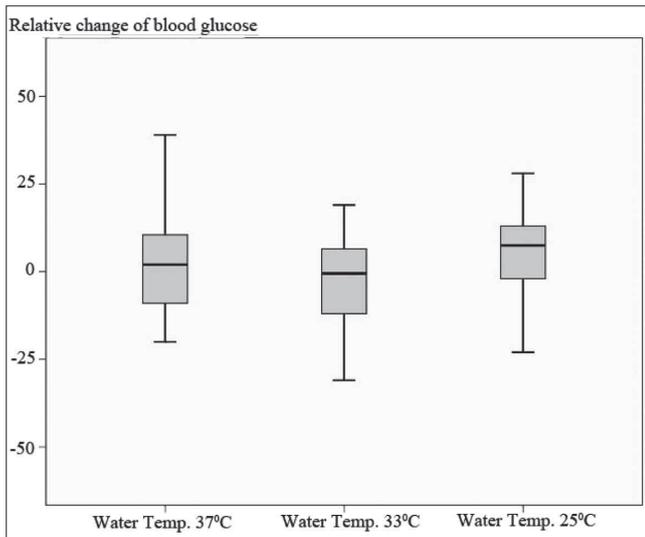


Fig 6. Relative change of blood glucose in dogs swimming in different water temperatures

Şekil 6. Değişik sıcaklıklardaki suda yüzen köpeklerde orantısız kan glikoz değişimi

After swimming in 37°C water, blood glucose level slightly increased, from 81.35 ± 10.61 g/dl to 81.90 ± 19.69 g/dl. After swimming in 33°C water, blood glucose increased from 76.90 ± 12.47 g/dl to 79.11 ± 14.26 g/dl. But swimming in 25°C water resulted in a significant increase ($P<0.05$) in blood glucose, from 79.05 ± 11.16 g/dl to 86.05 ± 19.09 g/dl (Fig. 5). However, the relative changes of blood glucose after swimming in different water temperatures were not significantly different (Fig. 6): 0.85 ± 20.44 , 0.94 ± 10.53

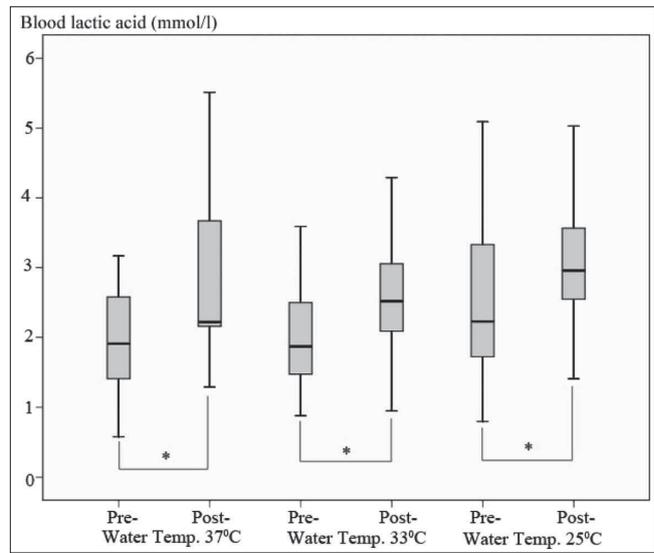


Fig 7. Comparative blood lactic acid levels between pre- and post-swimming in different water temperatures. A significant difference ($P<0.05$) was found between pre- and post-swimming at the same water temperature (*)

Şekil 7. Değişik sıcaklıklardaki suda yüzmeye öncesi ve sonrası orantısız kan laktik asit seviyeleri. Aynı sıcaklıktaki suda (*) yüzmeye öncesi ve sonrası anlamlı derecede fark ($P<0.05$) tespit edildi

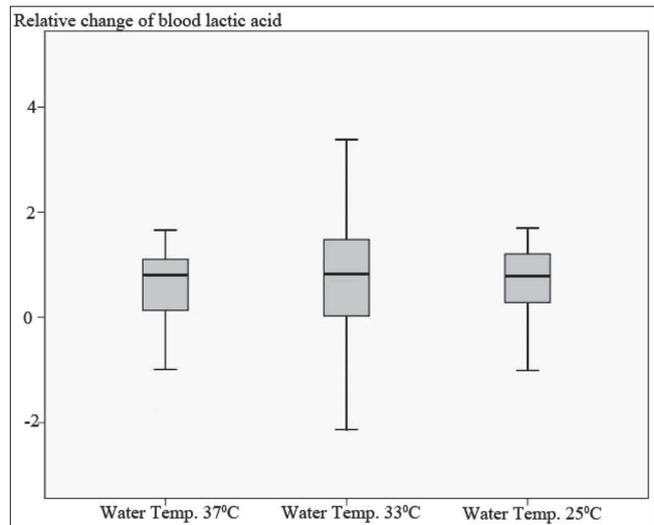


Fig 8. Relative change of blood lactic acid in dogs swimming in different water temperatures

Şekil 8. Değişik sıcaklıklardaki suda yüzen köpeklerde orantısız kan laktik asit değişimi

and 7.00 ± 14.39 in water temperatures of 37, 33 and 25°C, respectively.

For all three water temperatures, blood lactic acid level after swimming significantly ($P<0.05$) increased compared to pre-swimming (Fig. 7). Swimming in 37°C water resulted in a blood lactic acid increase from 1.23 ± 1.26 to 2.83 ± 1.07 mmol/l; in 33°C water, from 2.08 ± 0.82 to 2.89 ± 1.25 mmol/l; and in 25°C water, from 2.68 ± 1.22 to 3.48 ± 1.58 mmol/l. However, the relative changes of blood lactic acid after swimming in different water temperatures were

not significantly different (Fig. 8): 0.60 ± 1.07 , 0.81 ± 1.29 and 0.79 ± 1.05 in water temperatures of 37, 33 and 25°C, respectively.

DISCUSSION

Swimming has become increasingly popular in small animal medicine for purposes such as exercise and rehabilitation. This work is the first to report on the effect of water temperature on physiological changes in dogs. This study found that there were significant changes in heart rate, respiratory rate, body temperature, serum lactate and glucose level after swimming compared to pre-swimming. The results also showed a significant difference in heart rate and respiratory rate between the three water temperatures used in the experiment. However, there were some limitations of this study. Because the necessary instruments were not available, heart function, blood pressure, oxygen consumption and carbon dioxide production could not be measured.

Previous studies in rats and mice [9,11,18] as well as humans [13-15,19] have shown a decreased heart rate during swimming in cold water. In humans, a water temperature slightly lower than body temperature was found to decrease heart rate [20], while water temperature higher than body temperature resulted in an increased heart rate [16]. This can be explained by the fact that swimming in water with a temperature lower than body temperature can cause peripheral vasoconstriction, resulting in increased blood pressure. Higher blood pressure affects the baroreceptor reflex, causing a decreased heart rate with a consequent reduction in blood volume and, finally, decreased blood pressure [21]. When swimming in lower water temperature, the body's muscles require additional blood supply. This can result in a decrease in the amount of venous blood returning to the heart, which inactivates the baroreceptor reflex, causing an increase in heart rate. While swimming in a water temperature that similar to body temperature results in vasodilatation, which decreases blood pressure. This causes an increase in the heart rate in order to increase blood volume; however, this increase is less than when swimming in lower water temperature [10,12,22]. However, there is some evidence that conflicts with the changes mentioned above. A report by Graham [23] found no difference in heart rate among women during exercise in air temperatures of 5°C and 22°C. There are several factors that can influence changes in heart rate during exercise: level of exercise, relative workload, stress, shivering, increased muscle tone, and the sympathetic nervous system [12,23].

The present study found that swimming in 25°C water resulted in an increased heart rate, compared to the other two water temperatures; this result differed from other previous reports, as mentioned above [7,9,14]. Three possible explanations could account for the elevation of

heart rate in dogs during swimming in 25°C water. First, the levels of catecholamine (norepinephrine, epinephrine and dopamine) are higher during exercise in cold air and water [12]. For this reason, it is possible that the increased heart rate in cold water is an effect of catecholamine. It may also be noteworthy that the level of glucose in serum after swimming in 25°C water was found to be significantly elevated, while the other two groups showed no significant change. Second, a dog's hair can prevent vasoconstriction of the peripheral vessels on the skin; thus the blood pressure does not change, resulting in non-stimulation of the baroreceptor reflex and consequently no decrease in heart rate. In humans it was found that skin temperature was closely related to water temperature during swimming [24]; however this has not yet been proven in dogs. Finally, dogs began shivering while swimming in lower water temperature, which resulted in increased heart rate [25]. However, to conclusively confirm the reason that heart rate was elevated in dogs during swimming in lower temperature water, further experiments must be performed: for example, measuring differences in blood pressure during swimming in lower or higher water temperature than used in this study, and measuring some related hormones (i.e. adrenaline, noradrenaline, cortisol, insulin and glucagon).

In this study, the respiration rate in dogs swimming in 37°C water was found to be significantly increased compared with the other two water temperatures, 33°C and 25°C, in which the respiration rate decreased. Since dogs, unlike humans, do not have sweat glands on the skin, their body heat is decreased primarily from respiration and secondly from evaporation. Hence, swimming in higher water temperature can cause increased body heat, resulting in increased respiration rate [22]. The present study found that after 20 min of swimming in 37°C water, respiration rate was elevated by 67% compared to the resting period. Swimming in low water temperature resulted in lower heat production. Dogs were able to reduce body temperature via evaporation, resulting in decreased respiration rate. This study also found that respiration rate was down-regulated by 20% compared to the resting period after 20 min of swimming in lowest rate [12].

Animal hair functions to protect against environmental temperature [22]. To prevent the effect of the hair coat from interfering with accurate measurement of body temperature, the hair of all long-haired breeds in this study, i.e. Poodles and Pomeranians, was clipped to a length of 1 to 3 cm, similar to that of Chihuahuas.

Rectal temperature after swimming in 33°C and 37°C water was significantly increased compared to pre-swimming (1% and 1.5%, respectively). But after swimming in 25°C water, body temperature was significantly decreased (3%). The reason for the increase in body temperature during swimming in water that is close to body temperature is that dogs are not able to release heat from the body

when swimming in a water temperature similar to body temperature. But heat can be conducted from the body when dogs swim in low water temperature (25°C), resulting in a significant decrease in body temperature. Previous studies [9,26] have suggested that a change in body temperature during swimming is an important determinant of swimming capacity. The present results indicate that healthy dogs should swim in lower temperature water in order to prevent hyperthermia, as opposed to swimming in water close to body temperature.

Blood glucose after swimming in 33°C and 37°C water was not significantly different compared to pre-swimming; but after swimming in 25°C water, blood glucose was significantly higher (9%). However, the relative changes of blood glucose after swimming in the three different water temperatures were not significantly different. During exercise, epinephrine and norepinephrine inhibit insulin function, preventing glucose uptake into cells; they also activate glycolysis in the liver to increase the glucose level in blood [27]. Other studies in rats have also shown the same result [28-30]. However, this effect might be evident only during the first 20-30 min of exercise. Galbo and colleagues [13] reported that humans swimming in lower water temperature had higher serum glucose level during the first 20-30 min; after that time through the end of study (75 min), the level of serum glucose in humans swimming in higher temperature water was up-regulated to a greater extent than in the other groups. That study also found that the serum insulin level during the first 20-30 min in humans swimming in lower temperature water was higher compared to those swimming in higher temperature; but after that time through the end of study, the level of serum insulin in those swimming in higher temperature water was up-regulated to a greater extent than in the other groups.

Serum lactate can be used as an indicator of anaerobic metabolism during exercise [28]. In a rat model, serum lactate level was significantly increased after swimming in 25°C, 33°C and 37°C water [28]. This study also found a significantly higher level of serum lactate after swimming in every water temperature. The relative changes of serum lactate after swimming in the three different water temperatures were not significantly different. This was in accordance with a report by Mougios and Deligiannis [7], who found no significant difference in serum lactate between swimming in different water temperatures (20°C, 26°C and 32°C). However, other studies have shown a contrasting result [13,14]. Holmér and Bergh [14] reported significantly increased lactate when swimming in lower water temperature (18°C) compared to higher temperature (24°C and 34°C). They concluded that the higher lactate level from swimming in lower water temperature resulted from shivering. Another published report suggested that lactate level in the blood increased because of decreased blood supply to muscles due to vasoconstriction [31]. Other studies have

suggested that because the heart rate decreases in lower water temperature, the reduction in cardiac output results in decreased oxygen supply throughout the body, which in turn increases anaerobic metabolism [9,11]. Galbo and colleagues [13] also reported that during 75 min swimming, the serum lactate level in humans who swam in 21°C water was higher compared to those who swam in 33°C water. The peak level of serum lactate in humans was found after 5-15 min [13], depending on various factors: for example, type of exercise, intensity, level of exercise, and environmental temperature.

No reports have been published on serum lactate level in dogs during exercise, although several studies have been conducted in humans and rats [7,13,28,31]. The changes of serum lactate level during swimming are able to represent metabolic activity (anaerobic or aerobic metabolism), which can help the dog trainer or veterinarian in designing an appropriate exercise program. Future studies to determine serum lactate level during exercise under various conditions would also be useful for this purpose.

Therefore, the results of this study could increase veterinarians' understanding of the physiological changes in dogs during swimming in water at varying temperature. Most of the physiological responses in dogs during swimming are similar to those of other mammals. Based on the results of this study, swimming in a water temperature between 25-33°C is recommended for older dogs or for dogs with heart and/or respiratory disease in order to prevent tachycardia, hyperventilation and hyperthermia.

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