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The effect of postprandial exercise on mean blood glucose concentrations following high and maintenance carbohydrate content meals in healthy dogs

Chelsea L. Davis, Andrew C. Bugbee [*], Cynthia Ward

University of Georgia College of Veterinary Medicine, 2200 College Station Road, Athens, GA 30602, United States of America

A R T I C L E I N F O

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A B S T R A C T

Objectives: To compare the effect of 15 min of exercise 30 min post-meal on mean blood glucose concentrations in 5 well-conditioned versus 5 over-conditioned dogs. To compare the effect of exercise on glycemic control in dogs eating their maintenance diet as compared to a high carbohydrate meal.
Animals: Ten healthy staff or student owned dogs, five well- and five over-conditioned.
Procedures: This was a crossover study over 5 days. Continuous glucose monitors (CGM) were placed on day 1. On days 2 and 3, dogs received their maintenance diet and a high carbohydrate meal, respectively and were walked on the treadmill for 15 min following each meal. On day 4, dogs were given their maintenance diet in hospital without treadmill activity. On day 5, the CGM were removed. The mean blood glucose 30 min post-meal, during exercise, 15 min after completing exercise, and the 1–3 h period after completing the exercise were compared to detect any effect of exercise, diet composition, or body condition.
Results: Dogs consuming a high carbohydrate meal had a significantly higher mean blood glucose 15 min post-exercise. Mean glucose values at all time points following a high carbohydrate meal were significantly higher than mean glucose values on the non-exercise day.
Conclusions and clinical relevance: No impact of post-prandial exercise on glucose concentrations were identified in this study, however, the carbohydrate content of the meal impacted post-prandial glycemic responses in healthy dogs regardless of body condition. Evaluating the impact of post-prandial exercise in insulin-dependent or glucose-intolerant dogs is warranted to determine if these findings persist.

1. Introduction

Exercise is known to contribute to the reduction of blood glucose concentrations by increasing striated skeletal and cardiac muscle glucose uptake and utilization for energy in humans (Colberg et al., 2010). During exercise, muscles utilize both insulin-independent and insulin-dependent mechanisms to increase cellular glucose availability. Exercise-induced breakdown of internal glycogen stores to liberate glucose and contraction-induced increases in myocyte plasma membrane expression of the GLUT-4 glucose transporter can occur independent of insulin's presence (Colberg et al., 2010). Exercise does increase tissue insulin sensitivity, an effect that can persist for prolonged periods (hours) following cessation of the exercise event (Colberg et al., 2010). However, post-prandial muscular glucose uptake is primarily accomplished via insulin-dependent expression of GLUT-4. This allows the myocytes to utilize glucose at rest as well as store it in the form of glycogen to support future activity. In fact, most postprandial glucose is removed from circulation via skeletal muscle and therefore this is considered the rate-limiting step in blood glucose clearance (Colberg et al., 2010).

Multiple studies in humans have examined the timing of physical activity and the effect it has on blood glucose concentrations, triglyceride levels, and 24-h glycemic control. One study demonstrated that light activity post-meal reduced the rise in blood glucose after a high carbohydrate meal in both sedentary and trained women (Hostmark et al., 2006). In elderly adults who are at risk for impaired glucose tolerance, 15-min bouts of post-prandial walking helped improve their 24-h glycemic control compared to one 45-min session of sustained exercise per day (DiPietro et al., 2013). The effects of post-prandial exercise in veterinary patients has not been fully elucidated. This

* Corresponding author.
E-mail address: abugbee@uga.edu (A.C. Bugbee).

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includes the type of exercise performed, when it is performed in relation to meals, the duration of exercise, and the impact of meal composition. This could have implications in populations of performance or working dogs as well as therapeutic impacts on the management of conditions such as diabetes mellitus (DM).

Diabetes mellitus (DM) is one of the most common endocrine diseases in canine patients with prevalence estimated to be 0.32–1.33% depending upon the country evaluated (Nelson, 2014). If exercise following meals could improve or prevent moderate to severe post-prandial glucose elevations, then this could have implications for consideration as a component of veterinary diabetic management. Human studies have shown that diabetics who perform post-prandial exercise have better glycemic control (Haxhi et al., 2013). Many of these studies have utilized continuous glucose monitors (CGM) to assess glycemic responses. These technologies have been previously validated in canines and intermittently record the mean interstitial glucose concentration over periods of 3 to 14 days (Corradini et al., 2016; Wiedmeyer and DeClue, 2008). This method of glycemic assessment provides much more data for interpretation, allows a more physiologic evaluation of the patient's glucose patterns throughout the day and night, and enables glucose data to be obtained in the home environment without the need for hospitalization.

The objectives of this study were 3-fold. The first objective was to compare the effect that 15 min of exercise 30 min following a meal had on blood glucose concentrations in well-conditioned and over-conditioned healthy dogs. Second, to compare the effect of post-prandial exercise on blood glucose concentrations after a patient receives their maintenance diet compared to being fed a high carbohydrate meal. Lastly, to determine if there is a difference in blood glucose concentrations between well-conditioned and over-conditioned dogs when fed their maintenance or a high carbohydrate meal. The hypothesis was that post-prandial exercise would have no effect on blood glucose concentrations in well- or over-conditioned dogs after being fed either diet type. It was also hypothesized that the blood glucose of healthy dogs would be no different following a high as compared to maintenance carbohydrate content meal.

2. Materials and methods

2.1. Animals

Ten adult dogs owned by staff or students at the University of Georgia College of Veterinary Medicine were recruited; 5 with normal body condition and 5 that were over conditioned. A physical exam including body condition score (BCS), complete blood count, serum chemistry, and urinalysis were performed. Dogs were excluded from the study if appreciable signs of disease were noted on exam or biochemical analysis. One investigator (CLD) assigned the BCS, with 5 participants having a BCS of 4–5/9 (ideal body condition) while the remaining 5 dogs were recruited based on having a BCS of ≥6/9 (overweight body condition).

2.2. Experimental procedures

The study was approved by an institutional Clinical Research Committee prior to participant enrollment and each owner signed an informed consent form. The study was a prospective, cross-over design. The duration of study participation was 5 days for each enrollee. Each dog was presented to the teaching hospital on day 1 for placement of a CGM.[1] The first 24 h after monitor application allowed time for monitor calibration to the interstitium. On Days 2 and 3 of the study, each dog was presented in the morning after having been fasted for 12 h. Each dog then received their maintenance diet on Day 2, and a high carbohydrate meal[2] on Day 3. The high carbohydrate diet was a diet formulated for high activity dogs and chosen arbitrarily. The amount of the high carbohydrate food used was calorie controlled to closely match the dog's typical caloric intake. Thirty minutes after eating on both Days 2 and 3, the dog was walked on a treadmill[3,4] at a controlled speed (1 mile per hour) for 15 min. The first treadmill used was a land treadmill, however it required multiple personnel to keep dogs consistently on the treadmill. Therefore, the treadmill was changed to an enclosed underwater treadmill with no water put in the tank. The time delay between eating and treadmill exercise allowed for digestion, absorption, and interstitial fluid glucose concentration equilibration to post-prandial blood glucose concentrations. All dogs tolerated this exercise well 30 min after a meal. On Day 4, each dog was presented in the morning after a 12 h fast. On this morning, the dog received their maintenance diet and did not have any treadmill activity. This non-exercise day was used as the comparison day to account for any stress-induced effects the dog experienced from being in the hospital. All dogs ate their meals within 5 min and no dog vomited after eating on any study day. The list of maintenance diets and percent carbohydrate content on a dry matter basis are both listed in Table 1. The CGM was then removed and the glucose data table downloaded the morning of Day 5.

The mean blood glucose was calculated using the CGM results for the following time periods: the 30 min between eating the meal to start of exercise, during the treadmill exercise, the 15 min after completing the treadmill exercise, and the 1–3 h period after completing the treadmill exercise. These means were compared to detect any effect of exercise, diet composition, or body condition within the population of well- and over-conditioned dogs.

Table 1
Maintenance diets for each study participant with carbohydrate maximum estimates based on a percent dry matter of the food.

Dogs	Maintenance Diet	Estimates of MAX Carbohydrates based on % Dry matter
Dog 1	Purina ProPlan FOCUS Large Breed	43.6%
Dog 2	Hill's Ideal Balance Lamb & Rice	48.7%
Dog 3	Purina ProPlan Savor Lamb & Rice	41.1%
Dog 4	Purina Veterinary Diets JM	41.93%
Dog 5	Purina ProPlan Savor Chicken & Rice	41.1%
Dog 6	Purina Veterinary Diets DRM	42.95%
Dog 7	Purina ProPlan Savor Lamb & Rice	41.1%
Dog 8	Hill's j/d	50.9%
Dog 9	Purina ProPlan Savor Lamb & Rice	41.1%
Dog 10	Purina ProPlan SPORT 30/20	32.6%

Information collected from the Purina Veterinary Diet 2018 Product Guide and the 2018 Hill's: Key to Clinical Nutrition Product Guide. Hill's Science Diet Adult Advanced Fitness Original Dry Dog Food is estimated to contain 54.5% maximum carbohydrates based on percent dry matter.

[1] iPro2 Professional Continuous Glucose Monitoring device. Medtronic-Northridge, CA, USA.

[2] Hill's Science Diet Adult Advanced Fitness Original Dry Dog Food. Hill's Pet Nutrition- Topeka, KS, USA.

[3] Large DogTread Canine Treadmill. PetZen Products- Ogden, UT, USA.

[4] AquaPaws Underwater Treadmill System. Hudson Aquatic Systems, LLC-Angola, IN, USA.

2.3. Statistical analysis

All analyses were performed using SAS V 9.4 (Cary, NC). A significance threshold of 0.05 was used. Linear mixed models were used to analyze glucose measurements. The linear mixed model to make comparisons between diet types included fixed factors for diet (maintenance or high carbohydrate) and body condition and a diet by body condition score interaction factor. This model was run for each time period separately. Multiple comparisons were adjusted for using Tukey's test. The linear mixed model to make comparisons to the calibration day glucose measurements included a fixed factor for day/time. Multiple comparisons were adjusted for using Dunnett's test. All linear mixed models included a random intercept for each dog to account for within dog correlation of glucose values. Satterthwaite degrees of freedom method were used. Model residuals were examined to evaluate the assumption of normality.

3. Results

Ten dogs were enrolled in the study. The breeds included pit bull terrier ($n = 3$), corgi cross ($n = 2$), and 1 each of a Golden Retriever, Australian Shepherd mix, pit bull terrier mix, Weimaraner, and German shorthair pointer. The median age of the dogs in the over conditioned group was 9 years (5–11 years). The median age of the dogs with normal body condition was 7 years (5–8 years). The median body weight of the over conditioned dogs was 25 kg (12–27 kg). The median body weight of the normal dogs was 25 kg (23–38 kg). The median BCS for well-conditioned dogs was 5 (4–5). The median BCS for over-conditioned dogs was 7 (6–8).

3.1. Prior to exercise

Feeding a high carbohydrate meal resulted in a 16.5 mg/dL higher mean post-prandial blood glucose concentration in all dogs as compared to after maintenance diet consumption; however, this difference was not statistically significant ($p = 0.0935$). When comparing the effect of a maintenance versus high-carbohydrate meal within each BCS group, mean glucose concentrations were no different in the well-conditioned ($p = 0.8229$) or over-conditioned ($p = 0.3284$) dogs. When comparing the BCS groups, there were no significant differences in mean glucose concentrations between well-conditioned or overweight dogs after maintenance ($p = 0.9983$) or high carbohydrate ($p = 0.8890$) meals.

3.2. During exercise

There were no significant differences in mean glucose concentrations during exercise in all dogs when fed a high carbohydrate meal as compared to a maintenance diet ($p = 0.3537$). When comparing the effect of a maintenance versus high-carbohydrate meal within each BCS group, mean glucose concentrations were no different in the well-conditioned ($p = 1.0$) or over-conditioned ($p = 0.5388$) dogs during exercise. There were no significant differences in mean glucose concentrations during exercise between well-conditioned or overweight dogs following a maintenance ($p = 0.9993$) or a high-carbohydrate ($p = 0.6051$) meal.

3.3. 15-minutes post exercise

Mean post-prandial glucose concentrations 15-min following exercise were significantly higher (mean 17.9 mg/dL; 95% CI 0.2–35.6, $p = 0.0484$) when dogs had been fed a high carbohydrate meal as compared to a maintenance diet (Table 2). Comparing meal type, there were no significant differences in mean glucose concentrations at 15-min following cessation of exercise in well-conditioned ($p = 0.1415$) or over-conditioned dogs ($p = 0.5388$). Mean glucose concentrations were not different 15-min following exercise between well-conditioned and overweight dogs following a maintenance ($p = 0.9329$) or high carbohydrate ($p = 0.79800$) meal.

3.4. 1–3 hours post exercise

There were no significant differences in mean glucose concentrations 1–3 h post-exercise between high carbohydrate and maintenance diets in all dogs ($p = 0.1263$). Comparing meal type, there were no significant differences in mean glucose concentrations 1–3 h following exercise cessation in well-conditioned ($p = 0.8646$) or overweight ($p = 0.4104$) dogs. Mean glucose concentrations 1–3 h following exercise were not different between well-conditioned and overweight dogs following a maintenance ($p = 0.9934$) or high carbohydrate ($p = 0.9433$) meal.

3.5. Comparison to the non-exercise day

Mean glucose concentrations for all time periods (prior to, during, 15 min after, 1–3 h after exercise) following the high carbohydrate meal were significantly higher than those on the non-exercise day (Table 3). There were no significant differences in the mean glucose concentrations at any time period when comparing the maintenance diet day to the non-exercise day.

Table 3
Mean glucose comparison of both high carbohydrate and maintenance diet to calibration day: mean differences, 95% CI on differences and p-values. *, §, ‡, † indicate significance.

Day/Period		Day	p-value	Difference	95% Lower	95% Upper
Hi CarbPrior	vs.	Non-Exer	0.0022*	25.6055	7.2693	43.9417
Hi CarbTreadmill	vs.	Non-Exer	0.0017§	26.0833	7.7471	44.4196
Hi CarbTread Post Min 15	vs.	Non-Exer	0.0005‡	28.7333	10.3971	47.0696
Hi CarbTread Post Hr 1–3	vs.	Non-Exer	0.0077†	22.8893	4.5531	41.2256
MaintPrior	vs.	Non-Exer	0.6495	9.1567	−9.1796	27.4929
MaintTreadmill	vs.	Non-Exer	0.3431	12.1833	−6.1529	30.5196
MaintTread Post Min 15	vs.	Non-Exer	0.4698	10.8333	−7.5029	29.1696
MaintTread Post Hr 1–3	vs.	Non-Exer	0.1214	15.7933	−2.5429	34.1296

Table 2
15 Min Post Treadmill Glucose: Mean Differences, 95% CI on Differences and *p*-values.

Diet	BCS		Diet	BCS	p-value	Difference	95% Lower	95% Upper
Hi Carb		vs.	Maint		0.0484*	17.9000	0.1596	35.6404
Hi Carb	Good	vs.	Maint	Good	0.8403	9.0000	−25.8406	43.8406
Hi Carb	Overweight	vs.	Maint	Overweight	0.1415	26.8000	−8.0406	61.6406
Maint	Good	vs.	Maint	Overweight	0.9329	7.0000	−26.9049	40.9049
Hi Carb	Good	vs.	Hi Carb	Overweight	0.7980	−10.8000	−44.7049	23.1049

4. Discussion

In the present study, there were two unexpected but significant findings among healthy dogs. The first was the mean blood glucose in all dogs 15 min following exercise was significantly higher the day they were fed the high carbohydrate meal compared to the day they were fed their maintenance diet. Second, dogs fed a high carbohydrate meal and exercised had significantly higher mean blood glucose concentrations compared to when they consumed their maintenance diet with no exercise performed. This overall lower tolerance to higher carbohydrate food is especially intriguing given that these were otherwise healthy dogs based on physical exam and minimum database bloodwork evaluation.

In nondiabetic humans, source and amount of carbohydrates in a meal can account for 85–94% of the postprandial glucose variability (Wolever and Bolognesi, 1996). One study in healthy dogs evaluated 20 diets and the effects of starch, crude protein, and ether extract (primarily fats) on postprandial glucose concentrations. The results of this study revealed that the starch content had the most significant impact on postprandial glucose, with higher starch content leading to higher postprandial glucose concentrations. Amounts of crude protein and ether extract had negligible effects (Nguyen et al., 1998). Another study comparing 3 different diets in healthy dogs found that the diet with moderate carbohydrate (25% ME) lead to an average of 9% lower postprandial glucose compared to diets with higher carbohydrates (55% ME or 45% ME) (Elliott et al., 2012). It is interesting that the current study only documented higher glucose concentrations, regardless of body condition, after dogs were fed a high carbohydrate meal and exercised as compared to remaining sedentary after ingestion of their regular diet. With this hyperglycemic effect also being noted prior to the onset of exercise, it suggests the difference was related more to the meal's carbohydrate content as opposed to any effect of the exercise itself.

No clinically relevant changes were noted in the overall glycemic response to the addition of postprandial low impact exercise in the current study. While statistically significant differences were detected, most differences were < 30 mg/dL in magnitude. This was not unexpected as healthy dogs were enrolled and therefore expected to have normal glucose tolerance and insulin producing ability to minimize glucose variation. While glucose utilization is increased during exercise in healthy animals, there are conflicting reports on whether measured circulating glucose concentrations remain static, increase, or decrease during and/or after the exercise event. This variability likely reflects breed variation, the training level of the dogs evaluated, and other biochemical associated factors based on previously published reports. In general, while hepatic gluconeogenesis appears similar between diabetic and non-diabetic dogs during exercise, there are differences in the magnitude of transient cortisol, glucagon, and catecholamine concentration increases that could factor into the variable glucose responses. For example, untrained Beagles pushed to exercise for 60-min showed no change in plasma glucose concentrations (Chanoit et al., 2002), while racing Greyhounds did experience modest glucose elevations during and after sprint training (Snow et al., 1988).

Further study appears warranted to elucidate the effects of postprandial exercise on glucose concentrations in both healthy and diabetic dogs. Though dogs overwhelmingly develop insulin-dependent DM, they should still maintain insulin-independent mechanisms of glucose utilization within skeletal muscle. Human studies have shown that diabetics who perform post-prandial exercise have better glycemic control, however most studies evaluate subject with type-2 or insulin resistant DM (Haxhi et al., 2013). While exercise and any associated weight loss would be expected to improve glycemic control in type-2 DM, it is unclear what role exercise could play in insulin-dependent DM. A small population of diabetic dogs ($n = 3$) treadmill training 6-days per week for 4 weeks only demonstrated a significant reduction from baseline in glycated albumin concentrations without an impact on fasting blood glucose concentrations or total area under the curve assessments during the investigation period (Saeki et al., 2014). It has also been shown that insulin resistance in obese canines is related to the degree of adipose tissue present and that weight loss, and subsequent decrease in adipose tissue, can improve insulin sensitivity (German et al., 2009). While the current study did not find differences in glycemic responses between ideal and over-conditioned dogs, repeating this study in a population of insulin deficient dogs may yield different results. Further determination of the potential impact of various intensity, durations, or postprandial timing of exercise in diabetic, working, or performance dog populations would be warranted.

There were several limitations to the present study. First, this was a small sample size of dogs that may have been underpowered to detect a true difference in the effect of exercise. Second, we did not use more precise methodology for determining BCS. There was no effect noted in this small population size of body condition score on the mean blood glucose concentrations at any time point. This is interesting given the literature previously discussed on increased adipose tissue increasing insulin resistance. One way to improve this factor would be to use a Duel-Energy X-ray Absorptiometry (DEXA) scan, for example. This scan that is normally used to measure bone density can also be used to measure the percentage of muscle mass and fat. With an objective measurement, we could more accurately group dogs by body condition. Third, there was only 1 dog in the over-conditioned group considered to be obese (BCS 8–9/9). If glucose intolerance is significantly worse in obese dogs compared to overweight dogs, then the current study may have failed to detect this difference. Fourth, the controlled exercise used in this study (treadmill walking at 1 mile per hour for 15 min) was low intensity to mimic what the average pet owner could do with their pet on a daily basis. This intensity of exercise may have limited detection of a significant difference in the current study population that a higher intensity form of exercise could have induced. Fifth, during analysis it was noted that several of the maintenance diets contained a carbohydrate amount nearing that of the high carbohydrate diet used. These diets were grouped in this manner during the study based on the recommended feeding of the diet. We may have detected a more profound difference in post-prandial glucose concentrations between the diet types if the maintenance diets had lower carbohydrate level with less variation among them. There were no post-prandial elevations noted associated with this set of maintenance diets, however. Finally, while the CIGM used was well tolerated with no complications noted, the particular device utilized currently serves mostly research purposes as clinical CGM has largely transitioned to a flash-glucose monitoring system.

5. Conclusions

The current study documented a potential impact of diet composition and postprandial exercise on glycemic responses. Regardless of body condition and with similar postprandial exercise, healthy dogs fed a high carbohydrate diet had increased mean glucose concentrations 15 min following exercise as compared to consuming their regular diet. Additionally, all dogs fed a high carbohydrate meal experienced higher mean glucose concentrations before, during, and after exercise as compared to remaining sedentary after eating their regular diet. Further study into the impact of meal composition and postprandial exercise, especially within diabetic, working, and performance dog populations, is warranted.

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The authors declare that there were no conflicts of interest.

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