Serum biochemical values in sled dogs before and after competing in long-distance races

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Objective—To measure and compare blood values in sled dogs before and after long-distance racing.

Design—Prospective study.

Animals—17 adult sled dogs in the 1991 Iditarod Trail Sled Dog Race and 21 in a simulated sled dog race.

Procedure—Blood samples were obtained from 17 dogs 7 days before they began and after they finished (finisher group) or were eliminated from (nonfinisher group) the Iditarod Trail Sled Dog Race. Blood samples were also obtained from 21 dogs before and after a simulated sled dog race.

Results—In finisher-group dogs, BUN and uric acid (UA) concentrations were increased after racing; nonfinisher-group dogs had significantly lower postrace BUN and UA concentrations. Significant increases in creatine kinase (CK) and aspartate transferase (AST) activities were detected in all dogs after racing, and postrace values were higher in nonfinisher-group dogs, compared with finisher-group dogs. Mean alkaline phosphate activities were significantly increased after racing in nonfinisher-group dogs only. In dogs that ran the simulated race, postrace values for serum albumin, total protein, calcium, and potassium concentrations, as well as Hct, hemoglobin concentration, and RBC count, were significantly lower than prerace values. Postrace values for alkaline phosphate, alanine transaminase, AST, lactate dehydrogenase, CK, BUN, and UA were significantly higher than prerace values.

Clinical Implications—High CK activities are indicative of severe muscle degeneration and, in sled dogs, may represent a degree of muscle breakdown beyond which a dog cannot continue to work. Markedly high CK, and possibly AST, serum activities may be indicators of performance failure in sled dogs competing in long-distance races. (*J Am Vet Med Assoc* 1997;211:175–179)

Endurance sled dog racing is a popular activity in certain areas of the United States. In recent years, long races such as the Iditarod Trail Sled Dog Race and the Yukon Quest International Sled Dog Race have received increasing public and media attention as spectator events. This attention has been accompanied by heightened interest in the humane aspects of sled dog races and the welfare of dogs that compete. Long-distance races may cover more than 1,000 miles and entail multiple days of racing. During the race, some dogs may be removed from teams because of injury, fatigue, failure to perform, illness, or dehydration.[1] The decision to remove dogs from the race is made by team drivers and course veterinarians and usually is made on the basis of an injury or subjective assessments of the dog's behavior and performance.

Training and racing result in certain physiologic and biochemical adaptations in sled dogs. Energy and water requirements increase dramatically.[2] Increases in measurements of PCV values and RBC counts at rest are indicative of enhanced oxygen transport, which is necessary during peak training periods.[3,4] Similarly, in response to exercise, fit dogs have lower heart rates and rectal temperatures than unfit dogs.[5] Results of recent studies[4,6] of racing sled dogs indicate that prolonged periods of exercise are accompanied by specific biochemical changes that can be detected in the blood or serum. However, little is known about the importance of these changes and whether they are correlated with performance or onset of fatigue. Such information would be of value to sled dog mushers during periods of training and when selecting dogs for inclusion in a racing team. Identification of a reliable biochemical marker that is associated with strenuous or excessive physical exertion would also be of benefit to veterinarians who monitor the health and welfare of dogs during long-distance races.

The purpose of the study reported here was to compare serum biochemical changes between dogs that completed the 1991 Iditarod Trail Sled Dog Race and dogs that were eliminated from the team during the race. A subsequent race was conducted under conditions that simulated a portion of the Iditarod Trail Sled Dog Race to obtain additional serum biochemical data from racing sled dogs.

Materials and Methods

Iditarod Trail Sled Dog Race—A group (team) of 17 sled dogs that raced in the 1991 Iditarod Trail Sled Dog Race was studied. The course is located between Anchorage and Nome, Alaska and is approximately 1,100 miles long. The team of dogs that was studied comprised 13 males and 4 females between 3 and 11 years old. The dogs on the team that successfully completed the 13-day race were referred to as the finisher group, and the dogs that were eliminated from the team during the race were referred to as the nonfinisher group. The decision to eliminate dogs from the team was made by the driver, with assistance from a veterinarian. Dogs were eliminated at 1 of 26 checkpoints along the route.

Seven days prior to the race, blood samples were obtained from the 17 dogs. Dogs were conditioned for the race, but were in a rested state when samples were obtained. In association with the race, blood samples were obtained a

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second time from each dog after they were eliminated from the team or after they completed the race. Logistic and regulatory constraints prevented immediate sampling in some instances, but blood samples were obtained as quickly as possible after dogs stopped running. The mean lapse between the time dogs stopped running and the time of sample collection was 6.9 hours (range, 2.6 to 11.6 hours).

Blood samples were collected by means of cephalic venipuncture. Care was taken to prevent blood from freezing during collection and processing. Blood samples for CBC analysis were collected in tubes containing sodium EDTA[a] and stored in a cool container for shipment to the laboratory. Blood samples for serum biochemical analysis were collected in serum separator tubes, allowed to clot for 30 minutes, and then centrifuged at 127 X g in a portable centrifuge[b] that was carried to each site. Serum was immediately removed, frozen, and shipped on dry ice to the laboratory for analysis. Blood samples for lactate analysis were collected in sodium fluoride tubes, mixed with an equal volume of perchloric acid, and refrigerated for 5 minutes. Samples were then centrifuged, and supernatant was removed and frozen immediately. Complete blood counts were determined with an automated cell counter,[c] and chemistry profiles were determined with a clinical chemistry analyzer.[d]

Simulated sled dog race—A second study was conducted. To obtain additional biochemical data from dogs under more controlled conditions, a group of 21 dogs ran as a team in the manner of a typical sled dog race covering 170 miles. All dogs completed the entire distance. Dogs included in this portion of the study comprised 17 males and 4 females between 2 and 13 years old. Blood samples were obtained before the race when the dogs were in a trained, but rested, condition and within 30 minutes of completion of the race. Samples were processed in the manner described previously.

Statistical analysis—Simple comparison tests and ANOVA were used to identify significant differences between mean values for finisher- and nonfinisher-group dogs (status), mean blood values of pre- and postrace samples (time), and to identify the interaction between status and time. The Mann-Whitney *U* test (a nonparametric procedure) was used to compare mean serum enzyme activities between finisher- and nonfinisher-group dogs, because these blood values were found to have unequal variance. The Wilcoxon test or Student's paired *t*-test was used to compare test values of pre- and postrace samples. A value of $P < 0.05$ was considered significant.

Results

Iditarod trail sled dog race—Heavy snow conditions persisted throughout the race. The 9 finisher-group dogs completed the race in 12 days, 16 hours, 34 minutes, and 39 seconds. Eight dogs were removed from the team at 1 of 6 checkpoints along the course. Reasons for removing dogs from the team included limb or pad injuries (2 dogs), extreme fatigue or failure to perform (5), or diarrhea (1). Shortest and longest distances run by nonfinisher-group dogs were 272 and 802 miles, respectively.

Serum urea nitrogen and uric acid (UA) concentrations increased in response to endurance exercise. However, nonfinisher-group dogs had significantly lower postrace serum urea nitrogen and UA concentrations than did finisher-group dogs. Hemoglobin concentration was decreased significantly in finisher- and nonfinisher-group dogs when comparing prerace with postrace values (Table 1).

Serum enzyme activities varied considerably between individual dogs before and after racing (Table 2). Signifi-

Table 1—Serum and blood biochemical values of sled dogs before and after competing in the 1991 Iditarod Trail Sled Dog Race

Variable	Reference range	Finisher group (n = 9)		Nonfinisher group (n = 8)	
		Before race*	After race*	Before race*	After race*
Hemoglobin (g/dl)	13.5–19.5	15.5 ± 0.38[a] (13.7–17.6)	14.1 ± 0.34 (12.5–15.8)	15.9 ± 0.37[a] (14.5–17.6)	14.6 ± 0.33 (13.0–15.9)
Total protein (g/L)	5.5–7.1	6.4 ± 0.09 (5.9–6.7)	5.8 ± 0.13 (5.1–6.3)	6.6 ± 0.12 (6.0–7.1)	5.9 ± 0.14 (5.4–6.5)
Sodium (mEq/L)	146.0–154.0	150.2 ± 0.40[a] (149.0–152.0)	147.3 ± 1.0 (142.0–152.0)	151.0 ± 0.46[a] (149.0–153.0)	147.2 ± 1.2 (142.0–152.0)
Potassium (mEq/L)	3.9–5.1	4.7 ± 0.07[a] (4.3–4.9)	4.5 ± 0.12 (3.8–5.1)	4.6 ± 0.10[a] (4.3–5.2)	4.3 ± 0.18 (3.7–5.2)
Chloride (mEq/L)	114.0–122.0	117.1 ± 0.26 (116.0–118.0)	113.7 ± 2.1 (99.0–120.0)	116.8 ± 0.37 (115.0–118.0)	117.4 ± 0.92 (115.0–122.0)
Calcium (mg/dl)	9.6–11.6	10.5 ± 0.09[a] (9.9–10.7)	9.7 ± 0.16 (9.2–10.6)	10.5 ± 0.06[a] (10.2–10.7)	9.2 ± 0.28 (7.5–9.9)
Phosphate (mg/dl)	2.3–4.9	4.2 ± 0.13 (3.6–4.7)	4.2 ± 0.16 (3.6–5.0)	4.6 ± 0.19 (3.9–5.7)	4.1 ± 0.27 (3.4–5.7)
Lactate (mg/dl)	7.97 ± 0.54†	7.9 ± 1.64 (1.0–15.0)	11.4 ± 2.78 (1.0–25.0)	6.8 ± 0.92 (3.0–11.0)	10.1 ± 1.81 (1.0–17.0)
Urea nitrogen (mg/dl)	6.0–22.0	16.0 ± 1.11[a] (12.0–21.0)	27.3 ± 0.99[b] (23.0–32.0)	13.0 ± 0.96[a] (8.0–18.0)	22.0 ± 1.84 (16.0–30.0)
Uric acid (mg/dl)	0.2–0.6	0.3 ± 0.1[a] (0.0–0.8)	0.4 ± 0.03[b] (0.2–0.5)	0.1 ± 0.05[a] (0.0–0.3)	0.3 ± 0.03 (0.1–0.4)
Creatinine (mg/dl)	0.7–1.5	0.7 (0.6–0.8)	0.6 (0.5–0.7)	0.6 (0.5–0.9)	0.6 (0.5–0.8)

*Mean ± SEM (range). †Values from a group of rested Greyhounds.[12]
[a]Significant ($P < 0.05$) difference between before and after race means within groups. [b]Significant ($P < 0.05$) difference between finisher and nonfinisher groups within a time.

Table 2—Serum enzyme activities of sled dogs before and after competing in the 1991 Iditarod Trail Sled Dog Race

Enzyme activity (U/L)	Reference range	Finisher group (n = 9)		Nonfinisher group (n = 8)	
		Before race*	After race*	Before race*	After race*
Creatine kinase	31–217	142.9[a] (85–245)	472.9 (157–1,001)	156.5[a] (69–237)	1,565.1 (82–4,000)
Aspartate transferase	17–43	39.8[a] (25–62)	94.3 (51–157)	55.0[a] (18–94)	206.4 (48–575)
Alanine transaminase	17–73	103.1 (35–157)	103.6 (63–206)	110.9 (56–199)	217.0 (84–760)
Alkaline phosphatase	5–53	41.4 (17–105)	50.3 (19–193)	43.2[a] (25–77)	75.9 (41–150)
Lactate dehydrogenase	20–194	39.2[a] (9–92)	94.9 (49–188)	61.6[a] (26–174)	42.9 (14–61)
γ-glutamyltransferase	0–6	3.3 (0–7)	3.3 (0–9)	1.0 (0–3)	2.9 (1–4)

See Table 1 for key.

Table 3—Serum and blood biochemical values of 21 sled dogs before and after completing a 170-mile simulated race

Variable	Reference range	Before race*	After race*
RBC count (× 10⁹/ml)	5.65–8.49	6.4 ± 0.11ᵃ (5.8–7.3)	5.8 ± 0.13 (4.6–7.0)
Hemoglobin (g/dl)	13.5–19.5	16.3 ± 0.24ᵃ (14.7–18.6)	14.2 ± 0.33 (11.1–17.3)
Hct (%)	41.0–59.0	50.5 ± 0.56ᵃ (46.5–55.3)	43.4 ± 0.98 (33.7–51.4)
Total protein (g/L)	5.5–7.1	6.1 ± 0.16ᵃ (4.9–7.6)	5.6 ± 0.16 (4.0–7.5)
Sodium (mEq/L)	146.0–154.0	153.0 ± 1.8 (130.0–164.0)	151.9 ± 2.6 (132.0–192.0)
Potassium (mEq/L)	3.9–5.1	4.6 ± 0.08ᵃ (4.1–5.2)	4.3 ± 0.10 (3.7–5.5)
Chloride (mEq/L)	114.0–122.0	121.1 ± 1.5 (105.0–136.0)	124.7 ± 1.9 (109.0–155.0)
Calcium (mg/dl)	9.6–11.6	10.5 ± 0.20ᵃ (9.0–11.9)	9.2 ± 0.26 (6.2–12.1)
Phosphate (mg/dl)	2.3–4.9	3.7 ± 0.12 (2.8–4.8)	3.4 ± 0.10 (2.8–4.3)
Lactate (mg/dl)	7.97 ± 0.54†	12.1 ± 0.79 (5.0–18.0)	9.3 ± 0.71 (5.0–16.0)
Urea nitrogen (mg/dl)	6.0–22.0	17.2 ± 0.83ᵃ (9.0–25.0)	33.4 ± 1.7 (22.0–50.0)
Uric acid (mg/dl)	0.2–0.6	0.3 ± 0.03ᵃ (0.0–0.6)	0.7 ± 0.05 (0.4–1.2)
Creatinine (mg/dl)	0.7–1.5	0.8 (0.6–0.9)	1.0 (0.7–1.3)

See Table 1 for key.

cant increases in **creatine kinase (CK)** and **aspartate transferase (AST)** activities developed in all dogs in response to racing (pre- vs postrace values). Postrace mean CK and AST activities were substantially higher in nonfinisher- than finisher-group dogs, but these differences were not significant. Mean alkaline phosphatase activities were increased significantly after racing in nonfinisher-group dogs, but did not increase in finisher-group dogs. A significant interaction effect between time of sampling and status of dog was determined for **lactate dehydrogenase (LD)** activities. Finisher-group dogs had higher postrace LD activities and nonfinisher-group dogs had lower postrace LD activities, compared with prerace values.

Simulated race—Dogs in the simulated race completed the total distance in 2.5 days, running 70 miles on the first 2 days and 30 miles on the third day. Postrace values for serum albumin, total protein, calcium, potassium, RBC count, hemoglobin, and Hct, were significantly lower than prerace values. Postrace values for alkaline phosphatase, alanine transaminase, AST, LD, CK, serum urea nitrogen, and UA were significantly higher than prerace values (Tables 3 and 4).

Discussion

Dogs that compete in long-distance sled races undergo intense training and conditioning in preparation for these events. However, despite adequate preparation and good husbandry, dogs are sometimes removed from teams during races. A review of veterinary reports collected from checkpoints on the Yukon Quest International Sled Dog Race between 1987 and 1992 indicated that limb and pad injuries, diarrhea, and fatigue were the most commonly cited reasons for veterinary examination, and dehydration was cited as a primary concern.[1] It was also observed that a diagnosis of fatigue or performance failure by the musher or attending veterinarian is uniformly accepted as a justifiable reason for eliminating a dog from the race. In the study reported here, foot and leg injuries or diarrhea were responsible for the removal of 3 dogs from the race and 5 dogs were removed because of the more subjective assessment of fatigue or performance failure. These results are similar to those reported in a study[7] of dogs that ran in the 1993 Yukon Quest International Sled Dog Race. In that study, more than half of the dogs that did not finish the race were removed because of fatigue or performance failure.

Although dehydration is discussed anecdotally as an important concern in racing sled dogs, data from this study do not support dehydration as a cause of performance failure. Dogs thermoregulate primarily through evaporative water loss from expired air and secondarily through convection and radiation.[8] During endurance exercise, water turnover is high as a result of respiratory losses and increased urinary water loss. Results of a recent study[2] indicate that sled dogs running a 300-mile race have a mean water turnover rate of 250 ml/kg (114 ml/lb) of body weight. This high rate appears to be a result of the increased obligatory urinary solute load associated with a high energy intake. Exercise-induced hemoconcentration (dehydration) develops when the amount of water that is lost from the body is not adequately offset by fluid intake. Blood values indicative of dehydration are high measurments of Hct, RBC count, hemoglobin, and plasma protein.[4,9,10] Hemoglobin and total protein concentrations in the dogs of our study before and after racing were within reference ranges and indicated that hemoconcentration did not develop.

High serum creatinine concentrations also support a diagnosis of dehydration.[6] Creatinine is an end product of the metabolism of creatine phosphate in skeletal muscle. Normally, creatinine concentrations in the blood remain low as the result of efficient removal by the kidneys. Hypovolemia associated with dehydration leads to a decreased glomerular filtration rate, which, in turn, results in an increased serum creatinine concentration. Finisher- and nonfinisher-group dogs of the 1991 Iditarod Trail Sled Dog Race and dogs in the simulated race had serum creatinine concentrations that were within the reference range before and after racing (Tables 1 and 3). Collectively, these results indicate that dehydration was not a common problem in dogs in our study.

Table 4—Serum enzyme activities of 21 sled dogs before and after completing a 170-mile simulated race

Enzyme activity (U/L)	Reference range	Before race*	After race*
Creatine kinase	31–217	96.6ᵃ (55–265)	3,731.6 (121–47,920)
Aspartate transferase	17–43	26.9ᵃ (20–37)	262.8 (32–2,877)
Alanine transaminase	17–73	56.4ᵃ (22–113)	144.7 (41–586)
Alkaline phosphatase	5–53	35.8ᵃ (9–74)	90.6 (42–152)
Lactate dehydrogenase	20–194	65.4ᵃ (22–134)	170.4 (75–1,113)
γ-glutamyltransferase	0–6	3.4 (0–12)	5.3 (2–22)

See Table 1 for key.

Various disturbances in serum electrolyte concentrations and acid-base balance have been reported as the result of prolonged or intense exercise in human beings, horses, and racing Greyhounds.[11-14] In the study reported here, measurements of serum sodium, potassium, and chloride concentrations before and after racing were within the laboratory's reference ranges for healthy dogs. Serum sodium, potassium, and calcium concentrations were slightly, but significantly, decreased in response to exercise, but serum electrolyte concentrations were no different between finisher- and nonfinisher-group dogs of the 1991 Iditarod Trail Sled Dog Race. These results indicate that electrolyte imbalance was not a major concern during endurance exercise in these dogs.

High serum urea nitrogen and UA concentrations, like creatinine, can be indicative of a low glomerular filtration rate and impaired kidney excretion. However, because serum creatinine concentration did not increase in dogs in our study, high serum urea nitrogen and UA concentrations were probably the result of increased protein catabolism to provide energy for work. During prolonged exercise, protein oxidation can provide up to 10% of the energy needed by working muscles.[6,15] In the study reported here, finisher- and nonfinisher-group dogs had increased serum urea nitrogen concentrations in response to exercise. This effect was also observed in dogs that ran in the simulated race. Mean postrace serum urea nitrogen concentration of nonfinisher-group dogs was significantly lower than the mean postrace concentration of finisher-group dogs, but ranges of concentrations for each group were similar (Table 1). Examination of the data indicated that 3 nonfinisher-group dogs were removed from the team after completing only about a third of the race. Serum urea nitrogen concentrations for these dogs were between 16 and 22 mg/dl and accounted for the lower mean value in that group. It is likely that the shorter period during which these dogs were working resulted in a decreased need to oxidize amino acids for energy, resulting in lower serum urea nitrogen and UA concentrations. High serum concentrations found in dogs that were exercising for prolonged periods are consistent with previous reports of high serum urea nitrogen concentrations in dogs during a long-distance sled dog race.[6]

Measurement of serum lactate concentration after exercise provides an indication of the level of exercise intensity that a dog has engaged in, with more intense exercise resulting in high lactate concentrations.[12] Increases in serum lactate concentrations up to 20-fold have been observed in racing Greyhounds and increases up to fivefold have been observed in racing sled dogs.[11,12,16,17] It has been suggested that high serum lactate concentration may be a factor in performance failure in some racing sled dogs; however, dramatic increases generally are not observed in these dogs, because the aerobic metabolism of fatty acids provides the major source of energy for this type of exercise.[17-20] In the study reported here, performance failure was not associated with high lactate concentrations.

Physical performance and the onset of fatigue may be related to activities of certain enzymes in serum. Muscle enzymes are located within myofibrils, and the activity of these enzymes in serum of healthy, rested dogs is low.[20] Damage to muscle membranes as a result of physical exertion or disease causes release of certain enzymes into the serum, and measurement of their activities has been used to estimate the degree of muscle damage in many species.[21]

Creatine kinase is primarily found in skeletal muscle, myocardium, and brain tissue.[22] Because it has a half-life of only a few hours, high serum CK activity is indicative of recent, active muscle injury.[23] High serum AST activity is also suggestive of muscle damage, but is less organ specific than CK, because AST is also found in the liver.[20,21] However, AST has a longer half-life (50 hours) than CK, so measurement of this serum enzyme activity is useful in conjunction with CK to indicate whether muscle disease is continuing or resolving.[20] Serum LD activity is also high in human beings and horses after strenuous exercise, but results in dogs have been inconsistent.[6,7,12,20,22,24]

In the study reported here, finisher-group dogs had significantly higher postrace serum LD activities, compared with prerace values, and nonfinisher-group dogs had significantly lower postrace LD activities, compared with prerace values. Dogs in the simulated race had significantly higher postrace LD activities, compared with prerace values. It has been postulated that serum LD activity is less sensitive to muscle damage than CK or AST activity and may not increase until greater exercise stress has been attained.[24] It is known that LD catalyzes the conversion of pyruvate to lactate for the production of ATP in the glycolytic cycle. This is an anaerobic process, and high LD activity is associated with anaerobic metabolism. It was expected that finisher-group dogs would be exercising intensely by use of anaerobic metabolism immediately before finishing.

It is generally accepted that serum CK and AST activities increase in response to strenuous exercise and are indicative of muscle damage, but it is not known whether high serum CK and AST activities are correlated to the onset of fatigue or impaired performance in a working animal. Moreover, specific serum activities of these enzymes that are indicative of muscle damage are not known. Some researchers have suggested that an increase in serum or plasma CK activity during exercise is related to transient changes in the permeability of muscle cell membranes and does not indicate damage to muscle fibers.[9,11]

In the study reported here, all dogs had a consistent increase in serum activities of CK and AST in response to exercise. Nonfinisher-group dogs of the 1991 Iditarod Trail Sled Dog Race had substantially higher postrace mean values for CK and AST activities than did finisher-group dogs (Table 2). However, because of high variation among dogs, the difference between finisher- and nonfinisher-group dogs was not significant.

A comparison of absolute CK activities between studies is not recommended, because absolute values are influenced by age and sex of dogs and by the method of analysis that is used. However, it is still an important observation that serum CK activities of some dogs in this study were comparable to activities in dogs with clinical myocardial disease or primary muscular disease that have been reported.[20,23] These CK activities are indicative of severe muscle degeneration and, in racing sled dogs, may represent a degree of muscle breakdown beyond which a dog cannot continue to work. In a recent study[e] of necropsy results of 11 dogs that died suddenly during long-distance sled dog races, severe muscle necrosis, which was similar to histopathologic lesions found in animals with exertional rhabdomyolysis, was detected in some dogs.

Results of our study indicate that markedly high CK, and possibly AST, serum activities may be indicators of performance failure or fatigue in sled dogs competing in long-distance races. Given the observational nature of our study, problems associated with collecting blood samples for analysis during a long-distance race and the small number of dogs that were included, it is important that further research be conducted on the predictive value of serum CK and AST activities for racing sled dogs.

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[a]Vacutainer, Beckton-Dickinson Co, Franklin Lakes, NJ.
[b]Mobilspin, Vulcan Technologists, Grandview, Mo.
[c]Toa Medical Electronics Ltd, Kobe, Japan.
[d]Roche Diagnostic Systems, Nutley, NJ.
[e]Blake JE, Institute of Arctic Biology, University of Alaska, Fairbanks, Alaska: Personal communication, 1997.

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