

# Epidemiologic characteristics and management of polysaccharide storage myopathy in Quarter Horses

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**Objective**—To characterize onset and clinical signs of polysaccharide storage myopathy (PSSM) in a well-defined population of affected Quarter Horses, identify risk factors for PSSM, determine compliance of owners to dietary and exercise recommendations, and evaluate the efficacy of dietary and exercise recommendations.

**Animals**—40 Quarter Horses with PSSM and 37 unaffected control horses.

**Procedures**—Owners of horses with PSSM completed a retrospective questionnaire concerning their horse's condition.

**Results**—Between horses with PSSM and control horses, no significant differences were found in sex distribution (21 vs 15 females and 16 vs 22 males, respectively), temperament, muscle build, diet, or amount of turnout. In horses with PSSM, signs of muscle stiffness, muscle fasciculations, sweating, exercise intolerance, weakness, muscle wasting, reluctance to move, colic, abnormal gait, recumbency, lameness, and swollen muscles began between the age of 1 day and 14 years (mean age,  $4.9 \pm 3.5$  years). Five horses with PSSM developed acute muscle atrophy. Sixty-three percent (25/40) of owners fed the recommended diet, 55% (22/40) provided regular exercise, and 40% (16/40) followed both dietary and exercise recommendations. Owners of affected horses for which a decrease in severity or frequency of PSSM was not found did not follow the exercise, dietary, or both recommendations. All horses for which both dietary and exercise recommendations were followed had improvement in signs of PSSM.

**Conclusions and Clinical Relevance**—In addition to exertional rhabdomyolysis, signs of PSSM include acute muscle atrophy and gait abnormalities. It appears that PSSM can be managed by following dietary recommendations combined with gradual increases in daily exercise. (*Am J Vet Res* 2003; 64:1319–1327)

**P**olysaccharide storage myopathy (PSSM) is 1 form of exertional rhabdomyolysis (ER) that is most often found in Quarter Horse-related breeds.<sup>1</sup> It is a metabolic myopathy that results in excessive accumulation of glycogen, glucose-6-phosphate, and abnormal

polysaccharide inclusions in skeletal muscle.<sup>1,3</sup> The diagnosis of PSSM is made on the basis of finding periodic acid Schiff's (PAS)-positive inclusions that are resistant to amylase digestion in frozen sections of muscle biopsy specimens.<sup>1,2</sup> Others have suggested that excessive glycogen in the absence of complex polysaccharide may also be found in the muscle of horses with PSSM,<sup>4</sup> especially in the nondraft and non-Quarter Horse breeds.<sup>5-7</sup>

Clinical signs associated with PSSM in Quarter Horses include muscle stiffness, pain, shifting lameness, camped-out stance, and colic-like signs of pain.<sup>1,2</sup> The metabolic defect causing PSSM is unknown. Muscle glycogen metabolism appears to be normal,<sup>3,8,9</sup> whereas insulin sensitivity appears to be increased in Quarter Horses with PSSM, compared with clinically normal horses.<sup>10a</sup> Following oral or IV glucose challenge, horses with PSSM have a faster rate of removal of glucose from the bloodstream with lower insulin concentrations than clinically normal horses.<sup>10a</sup> Recommendations for the control of PSSM include feeding a low-starch, fat-supplemented diet that stabilizes blood glucose and insulin and providing a regular exercise regimen that enhances glycogen metabolism.<sup>1,11-13</sup> Results of previous reports<sup>11,13</sup> of various diets fed to a variety of breeds of horses, many of which had increased PAS staining for muscle glycogen with or without amylase resistant polysaccharide, indicate that increasing dietary fat ameliorates clinical signs of ER. In these studies, exercise regimes were not standardized,<sup>13</sup> and biopsy specimens were not always obtained to diagnose PSSM.<sup>11</sup>

The purpose of the study reported here was to characterize the onset and clinical signs of PSSM in a well-defined population of Quarter Horses that had abnormal polysaccharide inclusions identified in frozen sections of muscle biopsy specimens. In addition, aims of the study were to identify risk factors for horses with PSSM, compared with control horses, to determine compliance of owners to the specific dietary and exercise recommendations provided in writing at the time of diagnosis of PSSM and evaluate the efficacy of dietary and exercise recommendations. Evaluation of the response of horses with PSSM to the recommended dietary and exercise regimes will help clinicians make informed treatment and management recommendations.

## Materials and Methods

Seven hundred muscle biopsy specimens from horses were submitted to the University of Minnesota Neuromuscular Diagnostic Laboratory from January 1995 to July 2001 for evaluation of muscle disorders. A diagnosis of PSSM was made on the basis of the presence of abnormal

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PAS-positive inclusions in muscle fibers. Biopsy specimens were graded as mild (grade 1) if aggregates of granular polysaccharide were found in the cytoplasm, moderate (grade 2) if > 5 fibers were found that either were completely occluded or had substantial subsarcolemmal inclusions of crystalline polysaccharide, or severe (grade 3) if > 10% of the fibers contained inclusions of abnormal polysaccharide. From 180 horses determined to have PSSM on the basis of histologic findings on muscle biopsy specimens, 99 Quarter Horses and Quarter Horse-crossbreeds diagnosed with PSSM for at least 1 year were selected for the study.

All owners received written dietary and exercise management recommendations at the time of diagnosis. Dietary recommendations included feeding a minimum of 1% of body weight in forage/d, ideally as grass or oat hay. If it was necessary to feed alfalfa as a result of poor quality of grass hay, it was recommended that it comprise no more than 50% of the hay consumed. Removal of all concentrates containing grains and molasses was recommended. Supplemental energy could be provided in the form of alfalfa pellets with corn oil (up to 600 mL) or rice bran (0.5 kg/d for light exercise, up to 2 kg/d for heavy exercise). A vitamin and mineral supplement that balanced the calcium-to-phosphorus ratio of rice bran was advised. The aim of the diet was to provide < 10% of digestible energy (DE) as nonstructural carbohydrates (NSC) and 15 to 20% of DE as fat.

Exercise recommendations included providing regular routines and daily exercise. The maximum amount of daily turnout that could occur between periods of exercise was recommended so that the amount of time standing in a stall was kept to a minimum. Ideally, 12 to 24 hours of turnout was recommended, but the availability of extensive pasture turnout at each facility was variable. After changing the diet for 2 weeks, it was recommended to start exercising horses on a lunge line once a day for 5 minutes. The amount of exercise was then recommended to increase by 2 min/d. If stiffness was observed, slower increases in exercise were advised. Once horses could manage 15 minutes of trotting on a lunge line, a 5-minute break was advised, followed by further gradual increases in exercise. Once horses were able to manage 30 minutes of trotting on a lunge line, riding could be introduced at the same intensity and duration. It was recommended to allow at least 3 weeks before riding was initiated.

Horse owners were interviewed by telephone by 1 of 2 researchers (AMF or CJF) retrospectively to complete a standard questionnaire. Owners were also asked to answer the same questions on another healthy, unrelated horse with no history of ER in the same barn. Of the 99 horses with PSSM, 40 owners were available by telephone to complete a questionnaire. Thirty-seven questionnaires concerning control horses were completed. Reasons for failure to enroll affected or control horses were either unwillingness of owner to participate or failure to contact owner for various reasons (eg, owner moved away or changed telephone numbers). The survey included demographic questions and questions concerning activities prior to the onset of signs of ER, at the onset of clinical signs of ER but prior to diagnosis of PSSM, and subsequent to diagnosis and institution of dietary and exercise regimes for PSSM.

Interviewees were asked questions concerning the following: whether they were only the owner or both the owner and rider; sex of the horse (ie, mare, gelding, or stallion); whether the horse was alive; date of birth and age of the horse at the time of the interview; use of the horse (eg, pleasure, halter, cutting, reining, barrel-racing, dressage, racing, other); their perception of the horse's temperament (ie, very calm, calm, average, nervous, very nervous); their perception of the horse's muscle build (ie, average, below average, above average); whether the horse was tested for hyperkalemic

periodic paralysis (HYPP) and if so, what were the results; length of ownership; vaccination history; and whether the horse had any history of respiratory tract disease or other medical problems, including lameness. Information was collected about the diet and exercise routine before the onset of signs of ER, after the onset of signs of ER but before the diagnosis of PSSM, and after diagnosis of PSSM. The amount of exercise each horse received was categorized as no exercise, light exercise (< 30 minutes, infrequently), moderate exercise (< 1.5 h/d; 3 to 5 times/wk), and heavy exercise (> 1.5 h/d; 5 to 7 times/wk). In addition, information about the horse's stall and pasture routine, the length of time at pasture per day, and the size of the pasture was collected. Questions pertaining to diet included the type and quantity of hay per day, the type and quantity of concentrate per day, and the type of mineral or vitamin supplements fed.

Questions about episodes of ER were asked concerning the following: age at the onset of ER, clinical signs of ER observed (eg, stiffness, firm muscles, pain, weakness, muscle twitches, exercise intolerance, muscle wasting, a gait similar to that of draft horses with PSSM [ie, shivers-like gait], other), muscle areas most affected (eg, abdomen, back, hindquarters, and forelimbs), number of episodes of ER, season of ER occurrence, length of clinical signs of ER and stiffness (ie, ≤ 30 minutes, 31 minutes to 60 minutes, 61 minutes to 90 minutes, 91 minutes to 120 minutes, > 121 minutes), type of activity immediately prior to the onset of ER (eg, hand walking, on pasture, riding, lunging), length of exercise prior to signs of ER (ie, ≤ 10 minutes, 11 to 20 minutes, 21 to 40 minutes, > 41 minutes), gait at which the episode occurred (eg, walking, trotting, cantering, galloping), amount of stall rest prior to ER, and veterinary care that the horse received. Owners were asked whether they noticed any common factor associated with episodes of ER; whether myoglobinuria had been observed; and whether any dietary or exercise changes were implemented before a diagnosis of PSSM was made, and if so, the time of change in relationship to the diagnosis.

Owners were asked whether they observed any problem with the muscle biopsy sites (eg, scar, change in hair color, open wound, other) and whether the biopsy was a worthwhile procedure. The grade of PSSM, as determined on the basis of muscle biopsy specimen evaluation, was observed from the biopsy report. Compliance with dietary recommendations was assumed if horses were fed a low-grain fat-supplemented diet for at least 1 year or more following diagnosis of PSSM, and compliance with the exercise recommendations was assumed if horses received regular daily exercise and turnout. Owners were asked to provide the number of episodes of ER that had been observed since the diagnosis of PSSM and institution of the recommended dietary and exercise regimes (ie, 0, 1, 2 to 4, 5 to 7, 8 to 10, > 10) and whether they had noticed any change in ER since the diagnosis of PSSM (ie, decreased frequency, decreased severity, or no ER observed; less severe or more severe muscle stiffness; improved attitude to exercise, no change in attitude to exercise, or worse attitude to exercise).

Pedigrees were obtained from the American Quarter Horses Association for horses with PSSM, each dating back to at least 1940. Pedigrees were inspected for the number of times 2 stallions (A and B), previously implicated as founders for PSSM, were found on the sire's and dam's sides.<sup>14</sup> Pedigrees were not available for control horses.

**Analysis**—Data pertaining to the onset of signs of ER (prior to diagnosis of PSSM) and subsequent to diagnosis of PSSM was used from all 40 horses with PSSM. Data obtained was expressed in percentages and included the distribution of signs of ER observed, muscles affected, whether horses had ER at certain times of the year, the type and length of

exercise prior to ER, the number of times horses had clinical signs of ER prior to diagnosis of PSSM, dietary and exercise changes prior to diagnosis of PSSM, and the date of biopsy. The percent distribution of the type of hay and concentrate fed and type of exercise were determined. Continuous variables, such as the amount of concentrate (kg) and hay (flakes) fed after diagnosis of PSSM, were expressed as mean ( $\pm$  SEM) values. The number and severity of episodes of ER after diagnosis of PSSM and treatment were determined. A beneficial response to the fat supplemented diet and exercise regime was assumed if the number of episodes and severity of episodes reported by the owners decreased after diagnosis of PSSM.

Horses were categorized according to which type of diet they were fed after diagnosis of PSSM. Feed analysis for each horse was not performed. Horses in category 1 had grain eliminated and were fed a fat-supplemented diet. In general, these horses were fed < 10% of their daily caloric requirements in DE as NSC and  $\geq$  15% of DE as fat.<sup>15</sup> Horses in category 2 were fed some grain-based feed and a fat supplement; therefore, they were fed more calories in the form of NSC and less as fat, compared with horses in category 1. Owners of horses in categories 1 and 2 were considered to have complied with the recommended dietary regimes. Horses in category 3 were fed no grain and no fat supplement; therefore, they were fed < 3% of DE in the form of NSC as well as in fat.<sup>11</sup> Horses in category 4 were fed a reduced grain-based feed with no fat supplement. Horses in category 5 were fed the same or more of a grain-based diet without a fat supplement. The NSC content of diets of horses in categories 4 and 5 varied but likely contained > 20% of the DE in the form of NSC with a fat content of < 5% of DE.<sup>11</sup> Owners were recorded as complying with exercise recommendations if they reported that horses were exercised at least 3 times/wk and that the maximum amount of daily turnout they could provide at their facility was given between periods of exercise. To determine the effect of familiarity with the disease on the compliance with recommendations, we looked at the compliance of the owners of horses that had biopsies prior to 2000 with compliance of owners of horses that had biopsies from 2000 to 2001. The 37 control horses were matched by owner to 37 horses with PSSM to analyze demographic questions and activities prior to the onset of signs of ER.

Statistical analyses were conducted with the use of computer software programs.<sup>b,c</sup> Contingency table analyses ( $\chi^2$  test and odds ratio [OR]) were performed on categorical variables. A Student *t* test was used to compare continuous variables between affected and control horses. For all analyses, a *P* value of  $\leq$  0.05 was considered significant.

## Results

**Muscle biopsies**—Of the 40 horses with PSSM, 3 had muscle biopsies performed in 1995, 3 in 1996, 2 in 1997, 3 in 1998, 10 in 1999, 18 in 2000, and 1 within the first 7 months of 2001. Of the 40 muscle biopsy specimens, 15 were graded as mild, 12 were graded as moderate, and 13 were graded as severe, on the basis of the amount of abnormal polysaccharide accumulation.

**Clinical signs of horses with PSSM**—The mean age of onset of ER was  $4.9 \pm 3.5$  years and ranged from 1 day to 14 years old. The most common clinical sign of PSSM was ER, which encompassed firm muscles, signs of pain, stiffness, muscle twitching, sweating, weakness, and reluctance to move (Table 1). Less commonly observed signs during episodes of ER included mild colic, a shivers-like gait, recumbency, lameness, and swollen muscles. Muscle wasting was observed in

10 horses; 5 of these horses had muscle wasting without classic signs of ER. Exercise intolerance was reported between episodes of ER in 13 horses. Most horses (*n* = 35) had > 1 sign. Four of 40 horses were observed to have myoglobinuria after ER.

Thirty-three of 40 (83%) owners felt that their horse's hindquarter musculature was most often affected. Of the 40 horses, 15 (30%) had involvement of the back musculature, 10 (25%) of the forelimb musculature, 9 (23%) of the abdominal musculature, 2 (5%) of the neck musculature, 1 (2.5%) of the pectoral musculature, and 1 (2.5%) of the left hind limb only. Most horses (*n* = 35) had multiple areas of affected muscles. Duration of clinical signs exceeded 30 minutes for 27 of 30 (90%) horses with PSSM, and 12 of these horses had signs for > 2 hours.

Eight of 37 (22%) horses with PSSM, ranging in age from 2 to 9 years old, had a history of respiratory tract disease, compared with only 3 of 37 (8%) control horses (*P* = 0.05). Of these 8 horses with PSSM, 4 had a history of severe rhabdomyolysis and muscle atrophy associated with fever and respiratory tract disease. One additional horse had a history of severe rapid weight loss without respiratory tract disease. The 5 horses consisted of 2 mares, 2 stallions, and 1 gelding. Age at onset of signs ranged from 1 day to 1 year old. Four of the horses were alive at the time of owner interview, and the remaining horse was a foal that was euthanatized soon after onset as a result of severity of signs. Of the 5 horses that had signs of acute muscle atrophy with and without respiratory tract disease, a diagnosis of PSSM was made on the basis of histologic findings in the semimembranosus or semitendinosus muscle (*n* = 3), the gluteal muscle (1), and both the gluteal and semitendinosus muscle (1); 1 of these horses developed ER later in life. Three muscle biopsy specimens were graded as mild, and 1 biopsy specimen was graded as moderate. The remaining biopsy specimen was from the foal that was euthanatized, and it was graded as severe.

**Frequency of ER episodes**—Prior to diagnosis of PSSM in 40 horses, 17 (43%) had 1 to 3 episodes of ER,

Table 1—Clinical signs of 40 horses with polysaccharide storage myopathy (PSSM) during episodes of rhabdomyolysis

Clinical signs*	No. of horses (%)
Associated with ER	—
Firm muscles	29 (73)
Pain	26 (65)
Stiffness	25 (63)
Muscle twitching and fasciculations	18 (45)
Sweating	15 (38)
Weakness	12 (30)
Reluctance to move	8 (20)
Mild colic	5 (13)
Shivers-like gait	5 (13)
Recumbency	5 (13)
Lameness	1 (3)
Swollen muscles	1 (3)
Not associated with ER	—
Exercise intolerance	13 (33)
Muscle wasting	10 (25)

\*Most horses (*n* = 35) had > 1 sign. †Gait similar to that of draft horses with PSSM.

10 (25%) had 4 to 6 episodes of ER, 5 (13%) had 7 to 15 episodes of ER, and 2 (5%) had  $\geq 16$  episodes of ER. Six of 40 (15%) horses had never had clinical signs of ER. Of the 6 horses that never had clinical signs of ER, 4 horses had severe acute weight loss with respiratory tract disease, 1 had severe acute weight loss without respiratory tract disease, and 1 had a biopsy specimen submitted after being recumbent as a result of cranial trauma.

**Effect of season on ER episodes**—Ten of 34 (29%) horses with PSSM were considered to have episodes of ER during certain seasons. Owners recalled that 7 horses had ER during spring and summer and 3 during autumn and winter. The remaining 24 horses were not considered to have seasonal occurrence of ER. The 5 horses that had signs of acute muscle atrophy with and without respiratory tract disease and the 1 horse that had a biopsy specimens submitted after being recumbent as a result of cranial trauma were not included in this analysis.

**Veterinary treatment of horses with PSSM**—Thirty-four of 40 (85%) horses required veterinary attention. Treatments included administration of the following: flunixin meglumine (n = 24), fluids (IV or PO; 8), muscle relaxants or sedatives (5), phenylbutazone (3), dimethyl sulfoxide (3), and vitamin E and selenium supplements (3). Other treatments included hand walking and administration of diazepam, methylsulfonylmethane (MSM), dipyrone, prednisolone, trimethoprim-sulfadiazine, electrolyte supplements, and furosemide. In many affected horses, > 1 treatment was provided (n = 17).

**Type of exercise at the time of ER**—Twenty-four of 40 (60%) horses developed signs of ER during riding exercise, and 3 (8%) developed signs of ER during exercise on a lunge line. Three of 40 (8%) horses had signs of ER both while being ridden and lunged. Of the 40 affected horses, 1 (2%) had signs of ER during hand walking, 4 (10%) while at pasture, 4 (10%) while in a stall, and 1 (2%) while in a trailer. Of the 30 horses that were being exercised (by riding, on a lunge line, or

both) when signs of ER were observed, 19 (63%) had signs of ER after  $\leq 20$  minutes of exercise, and 11 (37%) were exercised for > 20 minutes before they developed signs of ER. Clinical signs of ER in the 30 horses were found at all gaits as follows: 6 (20%) horses were walking, 4 (13%) were trotting, 3 (10%) were cantering, and 1 (3%) developed signs of ER only at a gallop. Thirteen of the 30 (43%) horses had signs of ER at a variety of gaits.

Fourteen (35%) of 40 affected horses had undergone a period of stall rest before the first clinical signs of PSSM were noticed. Six of these horses had a period of rest lasting from half a day to 3 days. Two horses had a week of stall rest, 4 horses had 1 or 2 months of stall rest, and 2 horses were always kept in a stall.

**Demographics**—Of the 37 horses with PSSM included in the matched control study, 21 were female, and 16 were male (14 geldings and 2 stallions). Of the 37 control horses, 15 were female, and 22 were male (20 geldings and 2 stallions). No significant ( $P = 0.16$ ) difference was found in the sex distribution between the 2 populations.

The age of horses with PSSM at the time of owner interview did not differ significantly ( $P = 0.11$ ) from that of control horses. The mean age of horses with PSSM was  $7.0 \pm 3.91$  years (range, 2 to 16 years), and the mean age of control horses was  $8.4 \pm 4.89$  years (range, 2 to 19 years). At the time of owner interview, 5 of the horses with PSSM and 1 control horse were dead. Of the 5 horses with PSSM that were dead, 4 were euthanatized as a result of PSSM, and 1 was euthanatized as a result of severe rhabdomyolysis associated with respiratory tract disease. The control horse was reportedly euthanatized as a result of complications arising from *Sarcocystis neurona* infection.

No significant difference was found in the temperament of control horses versus horses with PSSM. Twenty-nine of 37 (78%) horses with PSSM were judged by their owners to be calm or very calm, compared with 28 of 37 (76%) control horses; 5 of 37 (14%) horses with PSSM had average temperaments, compared with 4 of 37 (11%) control horses; 5 of 37 (14%) of horses with PSSM were nervous, compared

Table 2—Concentrates fed to 37 horses with PSSM and 37 control horses prior to the diagnosis of PSSM

Concentrate	No. of horses with PSSM	No. of control horses	Mean amount fed (kg/d)	
			Horses with PSSM	Control horses
10% sweet feed	1	3	0.5	2
12% sweet feed	10	14	2	1.7
14% sweet feed	3	3	2.7	2.0
Alfalfa pellets	3	2	2.2	1.8
Corn and oats	10	9	NA	NA
Commercial <sup>a</sup>	2	0	2.3	0
Commercial <sup>d</sup>	2	4	2.1	2.8
High-protein supplement	2	2	0.5	0.34
Lush grass	1	0	NA	NA
Rice bran	0	3*	NA	0.5
No concentrate	2	3	NA	NA

For commercially available concentrates, please see corresponding footnote citations.  
<sup>a</sup>Significant ( $P < 0.05$ ) difference between horses with PSSM and control horses.  
 NA = Information not available.

with 5 of 37 (14%) control horses; and 2 of 37 (5%) horses with PSSM were described as aggressive, compared with no control horses. Four horses with PSSM were judged by their owners to have temperaments that were both calm or very calm and nervous.

No significant difference was found in the muscle build of horses with PSSM versus control horses. Most horses were described to have above average or average muscle build. Twenty-three of 37 (62%) horses with PSSM were judged by their owners to have above average muscle build, compared with 20 of 37 (54%) of control horses; 12 of 37 (32%) horses with PSSM had average muscle builds, compared with 14 of 37 (38%) of control horses; and 2 of 37 (5%) of horses with PSSM were considered to have a below average build, compared with 3 of 37 (8%) control horses.

Control (18/37) horses were 3 times as likely to be vaccinated against *Streptococcus equi* subsp *equi* ( $P = 0.03$ ) than horses with PSSM (8/37). No other significant difference in vaccination history was found between horses with PSSM and control horses. No significant ( $P = 0.49$ ) difference was found in the expression of lameness attributed to skeletal pain between the populations. Horses with PSSM (11/37 horses) were more likely to be tested for HYPP (OR = 4.78;  $P < 0.001$ ) than control horses (4/37 horses). However, no significant difference was found in the results of HYPP testing between control horses and horses with PSSM.

**Diet and exercise prior to diagnosis of PSSM**—No difference was found in the type of turnout, the length of time at pasture or size of pasture, or the amount or type of concentrate or hay fed between horses with PSSM and control horses prior to diagnosis of PSSM (Table 2 and 3). Control horses were more likely to be ridden, compared with horses with PSSM (OR = 8.4;  $P = 0.04$ ). Of the horses that were exercised (by riding or on a lunge line,  $n = 30$ ), no significant difference was found in the amount of exercise between the 2 groups. Eight of 37 (22%) horses with PSSM were in light exercise versus 9 of 37 (24%) control horses. Seventeen of 37 (46%) horses with PSSM were in moderate exercise, compared with 22 of 37 (59%) control horses. Five of 37 (13%) horses with PSSM were in heavy exercise, compared with 6 of 37 (16%) control horses.

No significant difference was found in the use of horses with PSSM or control horses. Of the 37 horses with PSSM and the 37 control horses, most were used for pleasure riding (14 [38%] horses with PSSM; 11 [30%] control horses), barrel racing (6 [16%] horses with PSSM; 9 [24%] control horses), cutting and reining (4 [11%] horses with PSSM; 7 [19%] control horses),

or jumping (2 [5%] horses with PSSM; 6 [16%] control horses). Other uses of the 37 horses in each group included breeding (3 [8%] horses with PSSM; 0 control horses), pasture rest (1 [3%] horses with PSSM; 0 control horses), showing (3 [8%] horses with PSSM; 2 [5%] control horses), eventing (2 [5%] horses with PSSM; 2 [5%] control horses), dressage (3 [8%] horses with PSSM; 2 [5%] control horses), halter (2 [5%] horses with PSSM; 1 [3%] control horse), driving (0 horses with PSSM; 1 [3%] control horse), and racing (1 [3%] horse with PSSM; 1 [3%] control horse). Six horses with PSSM were used for multiple purposes, compared with 3 control horses. Four of 37 (11%) horses with PSSM and 0 control horses were foals or untrained at the time of owner interview.

**Management after onset of signs of ER and prior to a diagnosis of PSSM**—Common management practices for ER prior to diagnosis of PSSM included vitamin E and Se supplementation, changing (reducing and increasing) dietary carbohydrate and protein, increasing dietary fat, vitamin B supplementation, and electrolyte supplementation. Of the 40 horses, 13 (33%) were rested (9 had stall rest, and 4 had pasture rest), 1 (3%) received increased exercise, 11 (28%) received decreased exercise, 5 (13%) received more regular exercise, 2 (5%) received less regular exercise, and 3 (8%) received more warm-up time during exercise. Of the remaining 5 horses, 4 were lost to follow-up (transferred to new owners from which specific details could not be obtained), and 1 was a foal that was euthanatized before any management could be implemented.

**Diet after diagnosis of PSSM**—All 40 owners received written dietary and exercise recommendations at the time of diagnosis. Of the 40 owners, 35 (88%) reduced the amount of dietary carbohydrates (diet categories 1, 2, 3, 4), 25 (63%) increased the amount of fat in the diet, 1 (3%) decreased the amount of fat in the diet, 6 (15%) decreased the amount of protein in the diet, 2 (5%) increased the amount of protein in the diet, and 10 (25%) supplemented electrolytes. Of 40 horses, 11 (28%) received a vitamin E and Se supplement, 1 (3%) was given a vitamin B supplement, and 1 (3%) was given MSM.

Specifically, of 40 horses, 16 (40%) were fed alfalfa hay or a mix of timothy and alfalfa hay, 18 (45%) were fed grass hay, and 3 (8%) were fed brome, bermuda, or coastal hay. Eight of 40 (20%) horses were not receiving any form of grain supplement (diet category 3), and 25 (63%) horses were fed rice bran or another fat supplement (eg, corn oil or commercially available supplements<sup>d,e</sup>; diet categories 1 and 2). Four of 40 (10%) horses were fed sweet feed (mean, 3.6 kg/d),

Table 3—Type of hay fed to 37 horses with PSSM and 37 control horses prior to the diagnosis of PSSM

Type of hay	No. of horses with PSSM	No. of control horses	Mean amount fed (flakes/d)	
			Horses with PSSM	Control horses
Alfalfa or alfalfa timothy mix	22	24	4.3	5.2
Timothy	10	10	4.8	5.1
Bermuda, brome, or coastal	1	3	2.0	3.3

and 6 (15%) were fed oats or oats and corn. One of 40 (3%) horses with PSSM was fed a commercially available diet.<sup>f</sup>

**Exercise following diagnosis of PSSM**—After a diagnosis of PSSM was made for 40 horses, 7 (18%) received increased exercise, 8 (20%) received decreased exercise, 21 (53%) were exercised more regularly, and 3 (8%) received less regular exercise. Warm-up exercise was increased in 5 of 40 (13%) horses, and 1 (3%) horse received an increased amount of exercise during the cool-off period. Eight of 40 (20%) horses with PSSM received an increased amount of pasture turnout, and 2 (5%) horses received a decreased amount of pasture turnout. Eight of 40 (20%) horses were retired to pasture.

**Compliance with dietary and exercise recommendations**—Of 40 owners, 19 (48%) eliminated grain-based feeds and fed a fat supplemented diet (category 1), 6 (15%) fed their horses some grain and a fat supplement (category 2), 8 (20%) fed no grain or fat supplement to their horse (category 3), 2 (5%) reduced the grain they fed to their horses but provided no fat supplement (category 4), and 4 (10%) continued to feed a grain diet without a fat supplement (category 5). The remaining horse was a foal that died before dietary recommendations could be implemented. For the 25 horses in which dietary recommendations were followed (categories 1 and 2), owners of 16 horses also followed exercise recommendations. For the 14 horses for which dietary recommendations were not followed, owners of 6 horses followed exercise recommendations. Owners of 8 horses followed neither recommendation, and 8 horses were retired to pasture.

Of the 40 muscle biopsy specimens evaluated, 21 (53%) were obtained from 1995 through 1999, and 19 (48%) were obtained after 1999. Of the 21 biopsy specimens submitted from 1995 through 1999, 11 were from horses for which dietary recommendations were followed, 8 were from horses for which exercise recommendations were followed, 5 were from horses for which both recommendations were followed, and 7 were from horses for which neither recommendation

was followed. Of the 19 biopsy specimens submitted after 1999, 13 were from horses for which dietary recommendations were followed, 14 were from horses for which exercise recommendations were followed, 10 were from horses for which both recommendations were followed, and 2 were from horses for which neither recommendation was followed. Owners of horses that had biopsy specimens obtained after 1999 were 2.0 times as likely to follow dietary recommendations ( $P = 0.3$ ), 4.6 times as likely to follow exercise recommendations ( $P = 0.02$ ), and 3.6 times as likely to follow both recommendations ( $P = 0.06$ ).

**Response to dietary and exercise regimes**—For determination of clinical response to dietary and exercise recommendations, 5 horses that had acute muscle atrophy and rhabdomyolysis with and without respiratory tract disease were excluded (Table 4). Eight horses that were retired to pasture after onset of ER were included in the analysis, because signs of ER were sometimes observed while these horses were on pasture. All 14 horses for which both dietary (categories 1 and 2) and exercise recommendations were followed simultaneously had improvement in the severity and frequency of signs of ER. This included 6 horses with grade 1 scores, 5 horses with grade 2 scores, and 3 horses with grade 3 scores for PSSM on histologic evaluation of muscle biopsy specimens. Of these 14 horses, 10 had no further signs of ER. Five of 6 horses for which exercise recommendations were followed and were not fed a fat supplement with or without a high starch diet (categories 3, 4, and 5) had a decrease in the severity of ER. The 6 horses included 2 horses with grade 1 scores, 2 horses with grade 2 scores, and 2 horses with grade 3 scores for PSSM on histologic evaluation of biopsy specimens. Of these 6 horses, 4 had no further signs of ER. Dietary recommendations were only followed for 8 horses. Of these 8 horses, 4 were retired to pasture, and 4 were exercised only occasionally. Five of these 8 horses had improvement in severity or frequency of ER, and 3 had no further signs of ER. The 8 horses included 2 horses with grade 1 scores, 1 horse with grade 2 scores, and 4 horses with grade 3 scores for PSSM on histologic evaluation

Table 4—Clinical outcomes of 35 horses\* that had a diagnosis of PSSM after compliance with dietary and or exercise recommendations

Exercise groups and diets	Horses	
	No. with a decrease in severity or frequency	No. with no further episodes of ER
Regular exercise		
Group A† Fat supplemented (categories 1, 2)	14/14	10/14
Group B No fat supplement (categories 3, 4, 5)	5/6	4/6
No regular exercise		
Group C Fat supplemented (categories 1, 2)	5/8 (20E, 3RP)	3/8 (20E, 1RP)
Group D No fat supplement (categories 3, 4, 5)	4/7 (30E, 1RP)	3/7 (20E, 1RP)

\*The 5 horses that had signs of ER in association with fever and weight loss with and without respiratory tract disease are not included. †Results for group A were significantly ( $P \leq 0.05$ ) different from that of group B, C, and D combined and from that of group C and group D alone.  
OE = Occasionally exercised. RP = Retired to pasture.

of biopsy specimens. Four of the 7 horses for which neither recommendation was followed had improvement in severity and frequency of signs of ER. Of these 7 horses, 3 were retired to pasture, and 4 were exercised only occasionally and included 2 horses with grade 1 scores, 2 horses with grade 2 scores, and 3 horses with grade 3 scores for PSSM on histologic evaluation of biopsy specimens. Of these 7 horses, 3 had no further signs of ER.

Horses for which both recommendations were followed (ie, 14/35 horses), compared with horses for which only 1 or neither recommendation was followed (ie, 21/35 horses), were significantly ( $P = 0.03$ ) more likely to have improvement in the severity and frequency of ER. Horses of owners that followed both recommendations were significantly ( $P = 0.04$ ) more likely to have improvement in severity and frequency of ER, compared with horses of owners that followed dietary recommendations only. No significant ( $P = 0.03$ ) improvement was observed between horses for which both dietary and exercise recommendations were followed, compared with horses for which only exercise recommendations were followed. However, this might be because only 6 horses were found for which exercise recommendations were followed without dietary changes.

**Value of muscle biopsies**—Biopsy specimens were obtained from the semitendinosus-semimembranosus musculature ( $n = 35$ ), gluteal muscles (2), biceps femoris muscles (1), or semitendinosus-semimembranosus and gluteal musculature (1), with 1 biopsy specimens site unrecorded. Thirty-seven of 40 (93%) owners considered the muscle biopsy worthwhile. Eight of 40 owners reported complications after muscle biopsy. All were open biopsies of the semimembranosus muscle with scarring ( $n=6$ ) and wound dehiscence (2). No complications from needle biopsies of gluteal muscle were reported.

**Pedigree analysis**—Pedigrees from 33 Quarter Horses were available for inspection. Sires A and B, identified as founders in a previous study,<sup>14</sup> were present in the pedigrees of 30 of 33 Quarter Horses. Sire A was present 51.5% (17/33 horses) of the time on both the sire's and dam's side in the pedigrees, 12% (4/33) of the time on the sire's side only, and 21% (7/33) of the time on the dam's side only. Sire B was present 21% (7 of 33) of the time on both the sire's and dam's side in the pedigrees, 30% (10/33) of the time on the sire's side only, and 18% (6 of 33) of the time on the dam's side only. These sires also feature prominently in randomly generated Quarter Horse pedigrees.<sup>14</sup> Pedigrees were not available for control horses in the present study.

## Discussion

Exertional rhabdomyolysis can be a sporadic occurrence in equine athletes or can be a chronic and frustrating condition for horse owners.<sup>16,17</sup> Histologic and physiologic studies of muscle biopsy specimens suggest that there are at least 2 forms of chronic ER.<sup>9</sup> **Recurrent exertional rhabdomyolysis (RER)** in Thoroughbred horses appears to be an abnormality in intracellular calcium regulation,<sup>9,18</sup> and PSSM in Quarter Horse-related breeds,<sup>2</sup> draft breeds,<sup>6</sup> and Warmbloods<sup>1</sup> appears to be a glycogen storage disorder. The epidemiologic findings in our study serve to highlight clinical differences between RER and

PSSM. Thoroughbred racehorses with RER are more likely to be 2-year-old fillies and have a nervous temperament, compared with racing Thoroughbreds that are not susceptible to RER.<sup>16,19</sup> In contrast to Thoroughbreds with RER, horses with PSSM had no sex predilection; no difference in temperament, compared with the control Quarter Horses; and began to have clinical signs of PSSM at an older age, when horses would begin consistent training ( $4.9 \pm 3.5$  years). Whereas signs of ER develop in most Thoroughbreds with RER after galloping or breezing,<sup>19</sup> they occurred most often in horses with PSSM after 10 to 20 minutes of combining walking, trotting, and cantering under saddle. This may in part reflect differences in training programs between race and pleasure horses. Lameness, even if it did not disrupt training, was a major risk factor for RER,<sup>19</sup> whereas this was not a significant risk factor for horses with PSSM. Thus, there appear to be clear differences in the factors initiating ER, with temperament playing an important role only in the Thoroughbred horses susceptible to ER.

Clinical signs of ER in Quarter Horses with PSSM are similar to those reported for various forms of ER and reflect generalized involvement of forelimbs and hindquarters, as well as back and abdominal muscles.<sup>1,2,17,20</sup> In our study, muscle pain with PSSM was quite severe, with clinical signs persisting for  $> 2$  hours in 30% of horses, recumbency in 13% of horses, and myoglobinuria in 10% of horses. A shivers-like gait (characterized by exaggerated flexion or abduction of the hindlimbs) was reported in 13% of the Quarter Horses during episodes of ER in our study and in a variety of breeds of horses that included Quarter Horses, which were reported to have PSSM by Valentine et al.<sup>11</sup> Five of 40 (13%) Quarter Horses with PSSM in our study had rapid muscle atrophy and severe acute rhabdomyolysis, and in 4 horses, this was associated with fever and respiratory tract disease. On histologic evaluation of semimembranosus-semitendinosus muscle biopsy specimens ( $n = 3$ ), gluteal muscle biopsy specimens (1), and both gluteal and semitendinosus muscle biopsy specimens (1) from these 5 horses, lymphocytic cuffing of blood vessels and infiltration of muscle fibers, which typifies the immune-mediated myopathy that has been described following exposure to *S equi*,<sup>21</sup> was not observed. The ages of the 5 horses with acute muscle atrophy in our study and the signs observed were similar to a group of 4 Quarter Horse fillies (2 yearlings and 2 two-year-old fillies) that were exposed to *S equi* without overt clinical signs of infection but developed signs of malaise and rapidly progressive atrophy of epaxial and gluteal muscles.<sup>21</sup> A rapid response to treatment consisting of penicillin and dexamethasone was found in these 4 fillies.<sup>21</sup> A rapid recovery was also found in the 4 horses with PSSM that had rapid muscle atrophy and severe acute rhabdomyolysis in our study. The remaining horse was a foal that was euthanized before treatment was implemented. The rapid atrophy in horses with PSSM could reflect an unrelated episode of immune-mediated myositis not evident in the particular muscle biopsy specimen or may be the result of an association between rhabdomyolysis and a concurrent disease in horses with PSSM. Muscle atrophy not attributed to a respiratory tract disease was reported in 8 of 61 draft and draft-related horses and ponies that had a diagnosis of PSSM by Valentine et al.<sup>6</sup>

Defined risk factors were not identified when comparing horses with PSSM and control horses in our study. This may be in part a result of the fact that in our study control horses had the same owner as horses with PSSM. This method of selection, however, was convenient and resulted in comparisons of populations that had received similar management. Ideally muscle biopsy specimens would have been obtained from control horses to rule out the possibility that they were affected with PSSM. However, it was not practical or financially possible to do this. One reason why only some horses have clinical signs of PSSM when managed in a similar fashion to other unaffected horses on the farm may be the result of an underlying genetic predisposition to the disease. A genetic predisposition to PSSM is suggested by a small breeding trial where 4 PSSM foals were produced by breeding mares with PSSM to a related stallion.<sup>22</sup> Results of previous analysis of the pedigrees of 18 Quarter Horses with PSSM indicated that 2 sires, A and B, figured prominently on both the sire's and dam's side of the pedigree.<sup>14</sup> These sires were present in the pedigrees of 30 of the 33 Quarter Horse pedigrees evaluated in our study but are also common in randomly generated Quarter Horse pedigrees.<sup>14</sup> Thus, the PSSM genotype may be found diffusely within the Quarter Horse breed, but phenotypic expression may be dependent upon the diet, amount of exercise, and exposure to respiratory viruses. Confusion of the signs of HYPP with PSSM may explain the 5 times higher frequency of testing for HYPP in the population of horses with PSSM, compared with control horses.

Although horses with PSSM and control horses were fed and exercised similarly prior to diagnosis of PSSM, findings in our study indicate that once a diagnosis of PSSM is made, altering the dietary and exercise regime can significantly impact the severity and frequency of ER in horses with PSSM. Although sample sizes were low, our data indicates that both exercise and dietary recommendations play a role in the resultant improvement of horses with PSSM regardless of the severity of the score given for the amount of abnormal polysaccharide in muscle biopsy specimens (Table 4). A decrease in exercise-induced clinical signs of stiffness could be expected with less exercise; however, some of the horses with PSSM in our study developed ER while at pasture. The magnitude of improvement reported for horses in our study is similar to those reported in previous studies<sup>11,13</sup> of dietary management of horses with various forms of ER. Because Quarter Horses with PSSM have enhanced insulin sensitivity, on the basis of results of IV and oral glucose tolerance testing, hyperinsulinemic euglycemic clamping, and insulin tolerance testing,<sup>10a</sup> it seems reasonable to conclude that a fat supplemented diet could provide a beneficial effect by providing energy without stimulating insulin secretion and glucose uptake into muscle cells.<sup>12,23</sup>

Owners changed their horses' diets more readily than their exercise routine. Difficulty finding the time to exercise a horse on a daily basis may in part explain why compliance with the recommended exercise regime was low. In the few horses where a fat supplement was not offered, but gradual daily exercise was

instituted, an obvious improvement in clinical signs of ER was also found (Table 4). Gradual daily exercise is likely beneficial, because it enhances the capacity for oxidation of glucose and fatty acids by skeletal muscle, and it may decrease muscle glycogen stores in horses with PSSM over time.<sup>22,24</sup> A training effect may be enhanced by turnout, compared with stall rest, as horses can travel on average 0.7 to 0.8 km/h further while on pasture.<sup>25</sup>

After 1999, more owners complied with the recommendations, possibly as a result of increased clinical recognition of the disease and encouragement to follow both dietary and exercise recommendations. Compliance with dietary changes could have been affected by palatability, expense, and availability of the rice bran products. Rice bran was recommended as a result of its high fat content (22.9% by weight,<sup>8</sup> compared with wheat bran of 3.8% fat by weight<sup>8</sup>), and over the period of our study, rice bran became more widely available, which may have improved compliance. In addition, pelleted forms of rice bran with higher palatability have become available.<sup>hi</sup> In a previous study of 5 diets of grass or alfalfa hay combined with soy oil, corn oil, or rice bran, most owners (68%) chose to maintain horses on a commercial feed with added fat, either in the form of rice bran or vegetable oil, because of convenience and palatability. Also, many horses found soy oil (8/19) and corn oil (4/19) unpalatable.<sup>13</sup> Unfortunately, commercial fat supplemented feeds often have high starch content,<sup>11</sup> and the NSC information is not provided on the feed tag.

There are no conclusive studies that identify the best form of dietary fat supplementation for horses with PSSM. Previous reports of clinical responses of horses with ER to dietary fat have included numerous breeds, numerous rations,<sup>13</sup> and in some instances, horses in which a diagnosis of PSSM was presumed without evaluation of muscle biopsy specimens.<sup>11</sup> Corn oil, soy oil, animal fats, and rice bran have all been suggested as dietary supplements for horses with exertional myopathies.<sup>11,11,13,26</sup> One investigator has suggested that rice bran should be carefully evaluated for horses with PSSM as a result of a potentially high NSC content of 22% on a dry matter basis.<sup>11</sup> However, results of a study<sup>12</sup> indicate that when used alone, rice bran produces little postprandial elevation in blood glucose and insulin. Thus at this point, on the basis of availability, convenience, and price, owners may choose to increase dietary fat in horses by feeding loose rice bran with a balanced mineral supplement, pelleted rice-bran with a balanced mineral supplement, or alfalfa pellets soaked in corn oil with added vitamin E. Because most horses with PSSM are only in moderate exercise, it is important that the caloric requirement of horses be considered, and a fat supplement added in amounts that will not contribute to obesity.

<sup>a</sup>Valberg SJ, Mickleson JR, Nahey D, et al. Glucose clearance in PSSM horses determined by euglycemic hyperinsulinemic clamp (abstr). *J Vet Intern Med* 2001;15:286.

<sup>b</sup>Epi Info, version 6.04 (CDC), Atlanta, Ga.

<sup>c</sup>Statistix, version 2.2 (analytical software), Tallahassee, Fla.

<sup>d</sup>Strategy, Purina Mills, St Louis, Mo.

<sup>e</sup>Ultimate Finish, Buckeye Feeds, Dalton, Ohio.

<sup>f</sup>Equine Senior, Purina Mills, St Louis, Mo.

<sup>a</sup>Microsteed, professional version 5.03, Kentucky Equine Research Corp, Versailles, Ky.

<sup>b</sup>Moorglo, Moormons Products, Quincy Ill.

<sup>c</sup>Re-Leve, Hallway Feeds, Lexington, Ky.

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