EQUINE VETERINARY JOURNAL
Equine vet. J. (1997) **29** (6) 454-458

Prospective study of equine colic risk factors

MARY K. TINKER*, N. A. WHITE†, P. LESSARD‡, C. D. THATCHER, K. D. PELZER, BETTY DAVIS† and D. K. CARMEL§

Department of Large Animal Clinical Sciences, Virginia-Maryland Regional College of Veterinary Medicine, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061 and †Marion duPont Scott Equine Medical Center, VMRCVM, Leesburg, Virginia 22075 and ‡University of California, San Francisco, California and §Department of Veterinary Sciences, VMRCVM, University of Maryland, College Park, Maryland 20742, USA.

Keywords: horse; colic; epidemiology; prospective; risk factors; logistic regression

Summary

A 1 year prospective study was conducted on 31 horse farms to identify risk factors for equine colic. Farms were randomly selected from a list from 2 adjacent counties of Virginia and Maryland, USA. The association between colic and farm or individual horse risk factors related to management, housing, pasture, use, nutrition, health and events was first examined by univariate statistical analysis. Individually significant (P<=0.25 for farm factors, P<=0.10 for horse factors) variables were used in a stepwise multivariable forward logistic regression to select explanatory factors (P<=0.05). Analysis was conducted at 2 levels: farm and individual horse with farm specified as a random effects variable. No farm-level variables were significant. Significant horse-level variables included: age, odds ratio (OR)=2.8 for horses age 2–10 years compared to <2 years; history of previous colic, OR=3.6 relative to no colic; changes in concentrate feeding during the year (1 per year, OR=3.6, more than 1, OR=2.2) relative to no changes; more than 1 change in hay feeding during the year, OR=2.1 relative to no changes; feeding high levels of concentrate (>2.5 kg/day dry matter, OR=4.8, >5 kg/day dry matter, OR=6.3) relative to feeding no concentrate; and vaccination with monocytic ehrlichiosis vaccine during the study, OR=2.0 relative to no vaccination. Feeding a whole grain with or without other concentrate components reduced risk, OR=0.4, relative to feeding no whole grain. Results of the study suggest that diet and changes in diet are important risks for colic in a population of horses on farms.

Introduction

Many causes have been suggested for equine colic, but only a few risk factors are supported by strong evidence. Parasites such as *Strongylus vulgaris* have been reported to cause a large proportion of colic cases (Becht 1984). Other studies have implicated small strongyles (Uhlinger 1990), tapeworms (Proudman 1993) and ascarids (DiPietro *et al.* 1983), but the cause of the majority of colic cases is unknown.

Nutritional risk factors include feeding a diet with an imbalance of roughage to concentrate (Snyder *et al.* 1988), feeding certain foodstuffs such as coastal Bermuda grass (Embertson *et al.* 1985; Pugh and Thompson 1992; Cohen and Peloso 1996), spoiled feed (Wheat 1975), young protein-rich grass (Huskamp and Kopf 1983), coarse, poor quality roughage (Embertson *et al.* 1985) and pelleted feeds (Morris *et al.* 1989), overfeeding (Wheat 1975), underfeeding (Rollins and Clement 1979) and feeding on the ground (Wheat 1975). Other risk factors suggested include inadequate water supply (Kiper *et al.* 1990; Pugh and Thompson 1992), changes in bedding (Owen *et al.* 1987), weather changes (Limont 1970; Rollins and Clement 1979), poor dentition (Meagher 1972), recent pregnancy (Huskamp and Kopf 1983; Snyder *et al.* 1990) or previous colic (Ducharme *et al.* 1983; Pascoe *et al.* 1983). These reports were anecdotal or are based on observations of case populations without any comparable control population; and reports that consider the role of management factors in colic are rare.

Two recent case control studies examined risk factors associated with management using multivariable analysis (Cohen *et al.* 1995; Cohen and Peloso 1996; Reeves *et al.* 1996). Both concluded dietary factors, changes in activity, pasture or housing and the Arabian breed were risk factors for colic.

This report includes results from a prospective cohort study of horses from a random sample of mid- to large size horse farms in Virginia and Maryland, USA. The objective was to determine if nutritional or management practices were associated with an increased risk of colic in a normal population of horses.

Materials and methods

Data collection

The case definition, study population, study design and case follow-up are described in the report of colic incidence for the same farms and horse population (Tinker 1995). At the initiation of the study, owners or their farm managers willing to participate were visited by investigators to collect farm history, a horse list, individual horse management profiles and samples of all feeds (Tables 1 and 2).

The owner or farm manager was given a calendar to record the occurrence of specified events or any changes in the profile for each horse. The owner was trained to use the calendar during the first interview, the events explained and calendar codes for the events provided. An instruction sheet with a complete list of events was left with the owner. Each farm was visited every 3 months to collect the calendars, update the horse-lists, profile new horses and sample new types of feed. The investigator followed a revisitation procedure to ask about events on the farm, the calendars were checked and any missing events added. Pastures were sampled on each farm during the spring, summer and fall. Nutrients were determined for the feed and pasture samples. Faecal samples were collected from 5 horses on each farm each season. The number of parasite eggs/g of faecal sample were counted by the MacMaster's method (Whitlock 1947). The proportion of positive faecal samples (>0 eggs/g) was determined for each farm.

Nutritional variables were defined based on each horse's diet

*Present address: US Dept. Agriculture-Animal Plant Health Inspection Service-Veterinary SVCS 236 East Second St, Geneseo, IL 61254, USA.

TABLE 1: Risk factors examined at the farm-level

Farm	State, time horses kept on farm* (<5 years), period farm owned by current owner* (<5 years), previous use of farm, current uses other than horse, major use of horses
Horses	Number of resident horses, visitor horses during the year, boarder horses* (nonresident horses boarded), horse number variation* (less than 10 horses moving on or off farm during year)
Employees	Employee number, proportion of part-time employees
Feedstuffs	Source, frequency of feeding concentrate, hay* (3 feedings/day), supplements and salt* (not feeding *ad lib*), methods of feeding, type of salt and supplement* (combinations of types), feeding order, delivery schedule, storage, feeding location, hay nutrient analysis
Water	Source, delivery system in stable* (automatic water delivery) and pasture, frequency of water checks and bucket cleaning
Habitat	Bedding type, frequency of stall cleaning and bedding changes*
Pasture	Forage type, soil type* (rocky soil), maintenance performed: fertilisation*, clipping, seeding, faeces removal, or rotation; pasture nutrient analysis
Health	History of disease in past 5 years: strangles, salmonella, gastric ulcers, foal pneumonia, rhinopneumonitis, potomac horse fever*, botulism, other disease*; parasite control programme, proportion of parasite egg positive faecal samples, record types

*Variable selected for logistic regression, $P<0.10$ for difference between categories in univariate testing; categories that increased colic are listed in parentheses.

recorded when the horse entered the study from the brand name or descriptions provided by the owner. Using the feed analysis values (Simons and Naylor 1991), dry matter intake of concentrates for each horse was calculated from the amount fed (number units fed/day x weight of one unit x dry weight percentage of the concentrate). The crude protein and digestible energy intake of concentrate were computed from the dry matter intake. The values of all concentrates fed to each horse were summed to obtain a total daily dry matter, protein and digestible energy intake. Concentrate intake was analysed as a continuous variable and as a categorical variable by ranking intake levels and assigning horses to approximate quartiles for each nutrient parameter, none, low, middle and high. Owner description of amount of hay fed was either an inexact measurement (flakes or bales) or free choice, therefore, hay intake was classified as free choice, measured or no hay. Crude protein and digestible energy for forages (hay or pasture) were examined only as farm variables, because calculation of intake for the individual horse was not possible without a measure of actual intake. Farms were categorised as having either high or low levels relative to the other farms for hay and spring, summer and fall pasture for these nutrients.

History variables were based on the most recent date reported prior to the start of the horse on the study. Since foals born in 1991 would have no opportunity to have a history of any problem and would distort the none category, they were excluded from the population used for these calculations.

Calendar entries completed by owners for each horse were classified by the investigators according to the type of event. A change was included if type, amount or frequency was altered from the original information obtained for the horse. Examples of changes were: starting feeding the current year's hay, changing from 2 scoops to one scoop of sweetfeed, feeding 3 times a day instead of twice, or beginning a different level of training. The number of events or changes during the year in each category was tabulated for each horse. Nutrition events were subclassified as changes involving concentrate, hay, bran or additive. Subclassifications of management events related to stable, pasture or paddock change and breeding, such as starting lights, were analysed as separate variables. Sub-categories of other management events were too small and heterogeneous to analyse. Health events were further classified by type, body system involved, time and diagnosis. Horses were classified by the number of treatments and anthelmintic type used for parasite control during the year: Ivermectin only, other product only, Ivermectin and another product, or none.

Because the horse population was dynamic, total horse days on the study were tabulated for each horse to allow for computation of incidence density based on the actual time the horse was under surveillance for colic. Colic cases were reviewed by the investigators to confirm that each case met the case definition. Complete data were collected for one year on each farm, with farms starting the study from November 1990 to January 1991 and completing between November 1991 and February 1992.

Analysis

Analysis was performed at both farm-level and individual horse-level. Risk factor variables were initially screened by univariate statistical tests and then stepwise forward logistic regression (Hosmer and Lemeshow 1989) was performed using EGRET[1] to select the most explanatory variables for colic (Table 3). Criteria for retaining a variable in the logistic analysis was $P<=0.05$. The variable with the largest change in deviance was retained at each step.

The univariate test for farm-level variables was a Kruskal-Wallis ANOVA, which was used to test for a difference in the incidence density of farms in different risk factor categories. Kruskal-Wallis ANOVA was used instead of categorical methods because farm incidence density was a continuous measure. Relative risk and other categorical methods were explored, but when farms were classified into high or low colic incidence categories many variables with zero values could not be analysed. Farm factors with a difference between categories ($P<0.25$) were tested as explanatory variables for high colic incidence in the farm-level logistic regression. A farm was classified a high incidence farm if it was in the top third of all farms ranked according to farm specific incidence densities (ID >0.1, n=11).

For horse-level variables, the incidence density ratio (IDR) was used as the univariate screening test. Incidence density (ID) for each exposure category of a variable was computed from the number of first colic cases experienced by horses in the category divided by the total horse days accumulated by the horses belonging to the category. The ratio (IDR) of the exposure category ID relative to the baseline category ID was computed with its confidence interval (CI) (Kleinbaum *et al.* 1982). A z-test was used to test whether the IDR was different from the baseline category.

Variables with any category with an IDR significantly different from 1($P<0.1$) was examined as an explanatory variable for colic in a random effects for distinguishable data logistic regression. Farm, age, gender, breed, use, work-time and stall time were identified as possible confounding variables prior to analysis. Farm was used as the random effects variable (Curtis *et al.* 1993). Odds ratios and confidence intervals for final selected variables were computed based on the best fitting model (Hosmer and Lemeshow 1989).

The contribution of farm as a random effect was tested by comparing the final model with the random effect term (%SCL) included with the model without the term and determining the significance of the difference (Anon 1990).

TABLE 2: Risk factors examined at the horse level

Horse	Gender, age* (2–10 years), breed* (Thoroughbred or Warmblood), residence time on farm, vices* (1 or more), cribbing*, *temperament** (not aggressive), pecking order position* (bottom)
Housing	Use of paddock, stall time/day* (9–24 h/day), stall bedding* (sawdust or shavings), pasture type, pasture and pasture size* (1 acre)
Use	Predominant use* (eventing), work schedule
Nutrition	Type diet* (concentrate and pasture or concentrate, pasture and hay), total dry matter from concentrate* (>2.5 kg/day), level of protein from concentrate* (>0.35 kg/day crude protein), level of digestible energy from concentrate* (>1 Mcal/day), type of concentrate* (pellet, sweetfeed or concentrate mix), *type of hay** (orchard grass hay), *type of pasture, feeding frequency** (feeding concentrate 2 or more times daily, feeding hay once or more than 2 times/day), feeding sequence* (variable sequence of feeding hay, grain and water), hay feeding method* (feeding measured amount), supplements* (used), additives, treats or bran* (bran fed daily or weekly), number of dietary components in addition to concentrate and hay* (2 or more supplements or additives in diet)
Health history reported for year before start of study (unless noted)	Previous colic* (colic in last 5 years), foaling, farrier visit, illness*, injury*, treatment or antibiotic*, anthelmintic treatment*, surgery within 5 years, vaccination in last year: any, tetanus, encephalomyelitis*, rhinopneumonitis*, influenza, rabies*, strangles, PHF; any problem in last month*, phenylbutazone* (use in month before study), other treatment or antibiotic (use in month before study)*, current drug administration
Events reported for the study year	Breeding, weaning, transport* (1–6 transports off or on the, farm), leaving and returning to farm, farrier visit, health events* (1 or more health events); veterinarian visits* (1–5 visits), drugs used* (1 or more drug treatments), nondrug therapy* (1 or more therapies), routine health care visits, diagnostic procedure* (>5 diagnostic tests), surgical procedures, health problems by body system: reproductive; gastrointestinal other than colic; skin; respiratory; musculoskeletal, nervous or related to hoof* (1 or more problems); dental; eye; or other; use of anti-inflammatory drugs without specified problem*, injury* (1 or more), fever, respiratory disease, lameness, number of health problems for year* (>5), number of different health problems* (>3), anthelmintic treatments, anthelmintic type* (ivermectin plus other anthelmintic), vaccination: any, tetanus, encephalomyelitis*, rhinopneumonitis, influenza, rabies, strangles, potomac horse fever*
Changes reported for the study year	Management* (1 or more changes), housing-pasture* (>4 housing changes), nutrition: all types* (>2 changes), Bran* (1 or more changes), hay* (>1 change), concentrate* (1 or more change), additive* (1 or more change), exercise* (1 or more change)

* Indicates the variable was selected for logistic regression, P<0.10 for difference between categories in univariate testing, categories that increased colic are listed in parentheses.

Results

Incidence density for first colic was 9.1 colic cases per 100 horse-years, based on 86 colics per 346,151 horse days (948 accumulated horse-years). The colic cases and study population have previously been described Tinker (1995).

Of the 77 farm variables, 15 were selected by univariate analysis to have categories with increased or decreased colic risk (Table 1). No variables were selected in the farm level logistic regression.

Out of 99 variables examined by univariate analysis, 54 horse variables were selected for increasing colic risk (Table 2). Final significant horse variables found by multivariable analysis are described in Table 3. The Hosmer-Lemeshow goodness of fit test indicated a goof fit for the model (P=0.69).

Several concentrate variables could be interchanged with concentrate intake in the logistic regression model. The concentrate intake variable most improved the model (P=0.0006 for inclusion in the final model); however, models with this variable replaced by concentrate feeding frequency (P=0.004) or concentrate type (P=0.016) were also valid. Odds ratios for concentrate type variables in an alternate model with type replacing dry matter intake are pellet, OR=6.1 (1.6–22.6), P=0.007; sweetfeed, OR=4.6 (1.4–15.6), P=0.01; mix with whole grains included or combination of concentrates, OR=2.9 (0.8–11.2), P=0.12; and whole grain only, OR=5.8 (0.8–45), P=0.09; relative to a forage only diet and whole grain in diet relative to no whole grain, OR=0.6 (0.2–1.5), P=0.29. Odds ratios for concentrate feeding frequency variables in alternate model with frequency replacing dry matter intake are 1/day, OR=1.0 (0.4–9.8), P=0.98; 2/day, OR=4.5 (1.4–15.2), P=0.01; 3 or more/day, OR=5.4 (1.5–18.8), P=0.009 relative to forage only. In the alternate models the odds ratios for the other variables were unchanged. The model would accommodate any one of 3 variables; however, if 2 concentrate variables were included, the model no longer differentiated between categories of either variable.

The role of the random effects variable was negligible on the whole model. The coefficient for the farm variable (%SCL) was very small and the difference between the model with and without the random effect was not significant (P=0.5). Age was the only potential confounder included in the final model, other than farm. Forcing breed, gender, stall-time, work-time and use into the final model made no change in the other variables selected or the size of the odds ratios, indicating they were not confounders.

Discussion

No previous studies have used a randomly selected population of healthy horses as the control when comparing factors for colic risk. Reeves *et al.* (1996) conducted a multi-centre case-control study using logistic regression to select significant variables. Their study differed from our study in several ways. The case definition was more exclusive including only horses with colic serious enough to be referred for treatment. Controls in their study were horses with other health problems. Although both studies had predominantly Thoroughbreds from the northeastern region of the US, horses in their study came from all sizes of farms.

Reeves *et al.* (1996) reported risk was increased for breeding horses compared to pleasure horses, Arabs compared to Thoroughbreds, horses cared for by trainers or managers compared to horses cared for by owners, horses with diets containing a high proportion of corn and horses without water in outside enclosures. Risk was decreased if horses had access to 2 or 3 pastures during the month before the colic compared with horses with no pasture access or if horses received a daily worming product. In our study, Arabians had a low colic incidence and the number and type of caretakers on the farm was not associated with the farm colic incidence density. Horses on pasture only had low risk and number of pasture and housing changes was not selected as a risk factor in multivariable analysis. Pasture use was addressed differently in our study and could not be compared. In our study, the role of corn in the diet was not examined because corn could not be distinguished from other diet components in commercially prepared concentrates that contained varying proportions of several grain products.

Cohen *et al.* (1995) compared 821 cases selected by practising veterinarians in Texas to match controls that were the next noncolic emergency treated by the same veterinarian. This case definition would probably select a similar case population as our study

TABLE 3: Variables selected by logistic regression using first colic for each case

Variable	P value	Odds ratio	95%CI
Age <2 years		1.0	
Age 2–10 years	0.02	2.8	1.2–6.5
Age >10 years	0.34	1.6	0.6–4.2
No history of colic		1.0	
History of colic in last 5 years	<0.001	3.6	1.9–6.8
No history of colic (1991 foal)	0.70	1.4	0.3–7.3
Concentrate = none		1.0	
Concentrate intake = <2.5 kg/day	0.20	2.4	0.6–8.8
Concentrate intake = 2.5–5 kg/day	0.01	4.8	1.4–16.6
Concentrate intake = >5 kg/day	0.004	6.3	1.8–22.0
No whole grain fed		1.0	
Whole grain fed	0.01	0.4	0.2–0.8
Concentrate events = 0/study		1.0	
Concentrate events = 1/study	<0.001	3.6	1.6–5.4
Concentrate events >1/study	0.02	2.2	1.2–4.1
Hay events = 0/study		1.0	
Hay events = 1/study	0.85	0.9	0.5–1.9
Hay events >1/study	0.01	2.1	1.2–3.8
No PHF vaccine		1.0	
PHF vaccine during study	0.005	2.0	1.2–3.6

PHF = Potomac horse fever.

because 68% of our colics were seen by a veterinarian (Tinker 1995). The breed makeup, predominant uses and farm size were different from the Virginia-Maryland population and many management and nutritional factors could be different due to locale. Risk factors identified through logistic regression by Cohen which support our findings included a history of previous colic, recent change in stabling in the past 2 weeks and recent change in diet.

Other reports are limited to comparisons of the age, breed and sex for colic cases with the proportions for the total hospitalised population at the same centre. Except for early studies that showed increased risk for Standardbreds (Sembrat 1975) and Arabians (Reeves *et al.* 1986), breed and sex has not been demonstrated as a colic risk factor. However, some case series do suggest gender or age are associated with risk for specific types of colic. Lipoma associated obstructions (Edwards and Proudman 1994) were related to older age and colonic volvulus were increased in mares with foal (Snyder 1990). With the broad definition of colic used in our study and a very low number of these diagnoses (1 lipoma, 1 colonic torsion) (Tinker 1995), these effects would not be distinguishable.

Information collected in our study depended on owner compliance and whether information was completely and consistently reported among farms throughout the period. Information was collected prior to identification of cases so that reporting should not differ for cases and noncases and it remained good for the year once the study was initiated.

Since nutrition, time and exercise categories were assigned based on information obtained at the start of the study, change in the information later in the year would be reported on the calendar as an event, but not reflected in the categorisation of farm or individual horse variables used in the analysis. Calendar reporting of an event appeared better for more clearly defined events. For example, PHF vaccination was a specific event and was expected to have been reported correctly. A possible source of measurement error could occur from under-reporting of changes. A change in exercise was reported for horses on only 21 (68%) of farms; therefore, this variable appeared compromised by underreporting. Owners may have varied in what they considered important to report for pasture/stable and management changes which may have resulted in reporting bias. Nutritional changes also could be influenced by whether the owner reported every small alteration in amount or frequency or just major changes in feed or frequency. The likeliest error was that horses with unreported events are misclassified as having zero events. This misclassification should be nondifferential, that is, error for horses without colic is equivalent to error for horses with colic, since the information was recorded before the horse was identified as a case. Under-reporting nondifferential error would decrease the IDR, making a risk factor less likely to be significant. Relative over-reporting by some farms would have negligible influence, since the total number of events were only used for assignment into broad categorical ranges.

Under-reporting could be a source of bias if the farms that reported less events and changes also reported less colic. If this occurred, it would be expected that all event variables would be significant. This was not seen, variables such as number of concentrate changes and hay changes were significant, while event variables such as number of farrier events or number of additive changes were not. The correlation between farm colic incidence density and number of events (all types) reported for a farm was r=0.34, indicating this was not an important bias.

A meaningful multiple logistic regression model for farm variables was not attained due to the low number of farms (n=31). The significance of these variables may have been undetectable due to lack of power. Alternatively, horse management on a farm may be variable enough between horses that management is best evaluated on the individual horse level for most variables. Farm-level variables selected in univariate testing were tried in the horse-level logistic regression, but none were significant.

Of the risk factors identified in this study, a history of colic has been identified previously (Ducharme *et al.* 1983; Pascoe *et al.* 1983; Cohen *et al.* 1995; Reeves *et al.* 1996). There is no information regarding why these horses appear more susceptible.

Highest risk was in the age 2–10 year group and age may be a confounder or a possible marker for use, training, exercise or nutritional factors. Numerous nutritional factors related to type, quantity, quality and diet or feeding schedule changes (Ralston 1991) have been cited as colic risks, with minimal epidemiological or experimental basis. Clarke *et al.* (1990) reviewed the physiological consequences of a high energy, low forage diet on the fluid balance, motility and microflora of the equine digestive tract. Clark's hypothesis that a high concentrate diet can cause disruption of the normal colon function supports our finding that higher concentrate intakes were associated with the highest colic risk.

Several interrelated aspects of concentrate feeding that could be altered to decrease a horse's risk of colic were selected as significant risk factors in this study. The concentrate variables related to the amount, type and frequency of feeding could be independently evaluated, but the interrelationships could not be determined. Based on the most explanatory of these variables the risk of colic increased 6-fold for horses at the highest concentrate intake levels over the horses on pasture who received no concentrate. Feeding high amounts of concentrate in 3 or more feedings a day did not reduce the risk associated with high levels of concentrate. Feeding a whole grain (oats, barley or other unprocessed grain) as part of the diet decreased the odds of colic relative to the horse receiving no whole grain. The more processed feeds like pellets or sweetfeeds increased odds for colic, whereas diets made up of combinations of different feeds or whole grains alone did not significantly increase odds relative to forage only diets. Horses with less easily digested, more complex or varied diets with a high proportion of forage, either hay or pasture, had less colic. This work suggests that type, intake and frequency of concentrate feeding are all important and should be examined.

Changes in concentrate feeding amount or type and more than the expected 1 change/year of hay were both strong risk factors.

This suggests that if the owner of horse makes multiple changes in the diet, the horse is at higher risk. In this type of logistic regression the time association of the nutrition changes to the colic events could not be evaluated.

No previous association between PHF vaccination and colic has been reported. Vaccination may represent a marker for health events for the horse and possibly for other management factors for the farm that have not been adequately defined or explored. The farms reporting a history of PHF prior to the study were marginally significant for increased colic on the farm univariate analysis. PHF vaccination was common, reported for 43% of horses, equivalent to the tetanus vaccination rate (43%) (Tinker 1995). Owners in the study region were highly aware of this disease and vaccination would be included in the health regimen of any horse with existing health problems, a farm with history of PHF problems or a history of colic or any farm on a high level of preventive medicine. In preliminary logistic regression attempts, variables related to number of health problems or number of treatments were significant in the model. However, when vaccination events were evaluated, other health variables were replaced by the variable for vaccination by PHF. Vaccination could have occurred following colic and is probably descriptive of the preventive health programme of the horse for the year rather than a cause of colic.

Parasites have been considered a major cause of colic (Becht 1984). All farms reported anthelmintic use for at least some of the horses on the farm during the year. We did not attempt to judge the adequacy of the anthelmintic programmes but, since a large proportion of the horses (88%) received regular administration, we did not expect to see parasites as a risk factor in this study. Variables relating to their use that were initially selected by univariate analysis included horses with no history of parasite control during the year before the study (1990) (ID=0.36) and horses with no reported parasite control during the study year (ID=0.15). The effect of these groups in the multivariable analysis was not seen because other explanatory factors were stronger and the number of horses without anthelmintic use was so low.

We conclude that previous colic, age 2–10 years, increased concentrate intake, changes in feeding and medical treatments increase the risk of colic on farms with 20 or more horses in Loudoun County, Virginia and Montgomery County, Maryland. Although we believe these results can be applied to similar horse populations, further investigation into the interrelationships of type, amount and frequency of feeding concentrates and clearer definition of time relationships of events with colic is recommended before they are used for specific management decisions. It appears from this study and the 2 recent case-control studies (Cohen *et al.* 1995; Reeves *et al.* 1996) that management and dietary factors are more important than previously acknowledged.

Acknowledgements

This research was supported by a grant from The American Quarter Horse Association and support from The Equine Research Fund.

References

Anon (1990) A heuristic introduction to random effects models. In: *Egret Reference Manual.* Statistics and Epidemiology Research Corporation, Seattle, Washington. pp 265-275.

Becht, J.L. (1984) The role of parasites in colic. *Proc. Am. Ass. equine Practnrs.* **30**, 301-311.

Clarke, L.P., Roberts, M.C. and Argenzio, R.A. (1990) Feeding and digestive problems in horses: Physiologic responses to a concentrated meal. *Vet. Clin. N. Am.: Equine Pract.* **6**, 433-449.

Cohen, N.D. and Peloso, J.G. (1996) Risk factors for history of previous colic and for chronic, intermittent colic in a population of horses. *J. Am. vet. med. Ass.* **208**, 697-703.

Cohen, N.D., Matejka, P.L., Honnas, C.M., Hooper, R.N. and T.E.C.S. Group (1995) Case-control study of the association between various management factors and development of colic in horses. *J. Am. vet. med. Ass.* **206**, 667-673.

Curtis, C.R., Mauritsen, R.H., Kass, P.H., Salmon, M.D. and Erb, H.N. (1993) Ordinary versus random-effects logistic regression for analyzing herd-level calf morbidity and mortality data. *Prev. vet. Med.* **16**, 207-222.

DiPietro, J.A., Boero, M. and Ely, R.W. (1983) Abdominal abscess associated with Parascaris equorum infection in a foal. *J. Am. vet. med. Ass.* **182**, 991-992.

Ducharme, N.G., Hackett, R.P., Ducharme, G.R. and Long, S. (1983) Surgical treatment of colic: results in 181 horses. *Vet. Surg.* **12**, 206-209.

Edwards, G.B. and Proudman, C.J. (1994) An analysis of 75 cases of intestinal obstruction caused by pedunculated lipomas. *Equine vet. J.* **26**, 18-21.

Embertson, R.M., Colahan, P.T., Brown, M.P., Peyton, L.C., Schneider, R.K. and Granstedt, M.E. (1985) Ileal impaction in the horse. *J. Am. vet. med. Ass.* **186**, 570-572.

Hosmer, D.W. and Lemeshow, S. (1989) *Applied Logistic Regression*. John Wiley and Sons, New York.

Huskamp, V.B. and Kopf, N. (1983) Right dorsal displacement of the large colon in the horse. *Equine Pract.* **5**, 20-29.

Kiper, M.L., Traub-Dargatz, J. and Curtis, C.R. (1990) Gastric rupture in horses: 50 cases (1979-1987). *J. Am. vet. med. Ass.* **196**, 333-336.

Kleinbaum, D.G., Kupper, L.L. and Morgenstern, H. (1982) *Epidemiologic Research, Principles and Quantitative Methods*. Lifetime Learning Publications, Belmont, California.

Limont, A.G. (1970) Symposium on equine abdominal surgery. IV. Observations on colic and abdominal surgery in the horse. *Equine vet. J.* **2**, 59-60.

Meagher, D.M. (1972) Obstructive disease in the large intestine of the horse: diagnosis and treatment. *Proc. Am. Ass. equine Practnrs* **18**, 269-279.

Morris, D.D., Moore, J.N. and Ward. S. (1989) Comparison of age, sex, breed, history and management in 229 horses with colic. *Equine vet. J., Suppl.* **7**, 129-132.

Owen, R.A., Jagger, D.W. and Jagger, F. (1987) Two cases of equine primary gastric impaction. *Vet. Rec.* **121**, 102-105.

Pascoe, P.J., McDonell, W.N. and Trim, C.M. and Van Gorder, J. (1983) Mortality rates and associated factors in equine colic operations: a retrospective study of 341 operations. *Can. vet. J.* **24**, 76-85.

Proudman, C.J. (1993) Are tapeworms associated with equine colic? A case control study. *Equine vet. J.* **25**, 224-226.

Pugh, D.G. and Thompson, J.T. (1992) Impaction colics attributed to decreased water intake and feeding Coastal Bermuda grass hay in a boarding stable. *Equine Pract.* **14**, 9-14

Ralston, S.L. (1991) Nutritional and feed-induced diseases in horses. In: *Large Animal Clinical Nutrition*. Eds: J.M. Naylor & S.L. Ralston. Mosby, St. Louis. pp 423-431.

Reeves, M.J., Hilbert, B.J. and Morris, R.S. (1986) A retrospective study of 320 colic cases referred to a veterinary teaching hospital. *Proceedings of the Equine Colic Research Symposium.* Veterinary Learning Systems. **2**, pp 242-250.

Reeves, M.J., Salman, M. and Smith, G. (1996) Risk factors for equine acute abdominal disease (colic): Results from a multicenter case-control study. *J. Prevent. Med.* **26**, 285-301.

Rollins, J.B. and Clement, T.H. (1979) Observations on incidence of equine colic in a private practice. *Equine Pract.* **1**, 39-42.

Sembrat, R.F. (1975) The acute abdomen in the horse: Epidemiologic considerations. *Arch. Am. Coll. vet. Surg.* **4**, 34-39.

Simons, J.C. and Naylor, J.M. (1991) Bioenergetics, basic concepts and ration formulation Eds: J.M. Naylor and S.L. Ralston. Mosby, St. Louis. pp 3-21.

Snyder, J.R., Pascoe, J.R., Meagher, D.M. and Spier, S.J. (1988) Predisposing factors and surgical evaluation of large colon volvulus in the horse. *Proc. Am. Ass. equine Practnrs.***34**, 21-28.

Snyder, J.R., Pascoe, J.R., Olander, H.J., Hinds, D.M., Young, R. and Tyler, W.S. (1990) Vascular injury associated with naturally occurring strangulating obstructions of the equine large colon. *Vet. Surg.* **19**, 446-455.

Tinker, M.K. (1995) *A Farm-based Prospective Study for Equine Colic Risk Factors and Risk Associated Events.* PhD Thesis. Virginia Polytechnic Institute and State University.

Uhlinger, C. (1990) Effects of three anthelmintic schedules on the incidence of colic in horses. *Equine vet. J.* **22**, 251-254.

Wheat, J.D. (1975) Causes of colic and types requiring surgical intervention. *J. S. Afr. vet. Ass.* **46**, 95-99.

Whitlock, H.V. (1947) Some modifications of the McMaster helminth egg counting technique apparatus. *J. Counc. Sci. Ind. Res.* **21**, 177-180.