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Evaluation of equine breeding farm management and preventative health practices as risk factors for development of *Rhodococcus equi* pneumonia in foals

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Objective—To determine whether foal management practices, environmental management, and preventative health practices are risk factors for development of *Rhodococcus equi* pneumonia in foals.

Design—Prospective matched case-control study.

Animals—2,764 foals on 64 equine breeding farms with 9,991 horses.

Procedure—During 1997, participating veterinarians completed paired data collection forms for comparison; 1 for an affected farm (containing ≥ 1 foal with pneumonia caused by *R equi)* and 1 for a control farm. Information collected pertained to stabling facilities, environmental management, foal husbandry, and preventative equine health practices.

Results—Matched farm data compared by use of conditional logistic regression indicated that personnel on affected farms were more likely to attend foal births, test foals for adequacy of passive immunity, administer plasma or other treatments to foals to supplement serum immunoglobulin concentrations, administer hyperimmune plasma prophylactically to foals, vaccinate mares and foals against *Streptococcus equi* infection, and use multiple anthelmintics in deworming programs. Affected farms were also more likely to have foals that developed other respiratory tract disorders and were approximately 4 times as likely to have dirt floors in stalls used for housing foals as were control farms.

Conclusions and Clinical Relevance—*Rhodococcus equi* pneumonia does not appear to be associated with poor farm management or a lack of attention to preventative health practices. Housing foals in stalls with dirt floors may increase the risk for development of *R equi* pneumonia. (*J Am Vet Med Assoc* 2003; 222:476–485)

Rhodococcus equi is considered the most common cause of severe pneumonia of foals aged 3 weeks to 6 months.[1-5] This organism has also been associated with extrapulmonary disorders of foals including enterocolitis, lymphadenitis, nonseptic polysynovitis, and osteomyelitis.[6,7] The pathogenesis of *R equi* infection in foals is incompletely understood,[2,3,8-11] but foals are primarily exposed to the organism through the respiratory and alimentary tracts.[3,12-15] Prevalence and case fatality rates are high.[16] Methods for control and prevention of *R equi* pneumonia remain elusive. Presently, there are no effective vaccines available, and treatment with hyperimmune plasma is expensive, labor-intensive, and impractical or ineffective in some instances.[17-21]

At present, data regarding risk factors associated with disease acquisition and transmission are limited. Identification of risk factors through appropriately designed epidemiologic studies is important to provide information about farm characteristics and management procedures that increase the risk for development of *R equi* pneumonia in foals. Other studies[22-36] have described the epidemiologic characteristics of this disease, but few have assessed management and preventative health practices as risk factors. There may be environmental factors, farm characteristics, farm management procedures, or preventative health practices that are associated with risk of *R equi* pneumonia. Such risk factors may be altered on endemic farms to decrease the prevalence and economic impact of *R equi* pneumonia in foals. The purpose of the study reported here was to determine whether specific farm management and preventative health practices are risk factors for the development of *R equi* pneumonia in foals on breeding farms.

Materials and Methods

The study reported here was performed in conjunction with a study[37] to identify farm characteristics associated with development of *R equi* pneumonia in foals on equine breeding farms in Texas. Study design and methods of data collection have been reported previously.[37] Briefly, participating veterinarians were asked to complete data collection forms for 1 affected breeding farm and 1 control breeding farm for which they provided primary veterinary services during 1997. A breeding farm was defined as a farm that raised at least 1 foal in 1997; an affected farm was defined as a breeding farm on which at least 1 foal developed pneumonia caused by *R equi* during 1997. A control farm was defined as a breeding farm with no history of *R equi* pneumonia in foals and on which no foal developed *R equi* pneumonia in 1997. Foals included in this study were 3 to 24 weeks old. Foals with clinical signs of pneumonia were considered to have *R equi* pneumonia if *R equi* was isolated from a tracheobronchial sample or postmortem lung specimen, or if at least 2 of the following were identified: multifocal pulmonary opacities visible on thoracic radiographs, ultrasonographic

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evidence of pulmonary abscesses, gram-positive intracellular coccobacilli observed during cytologic evaluation of transtracheal wash specimens, and history of *R equi*-related disease on the premises. Resident mares were defined as mares that were housed permanently on the farm, and transient mares were defined as mares brought temporarily to the farm for breeding or foaling. A mare and her foal were defined as a dam-foal pair.

General information regarding farms—General information was collected for each affected farm and each control farm as described.[37]

Foal and environmental management and preventative health practices—Information recorded about foal management, preventative health practices, and environmental management included place of birth (foals born on the farm or elsewhere); whether pregnant mares were transported to other premises for parturition; location on the farm where foals were born (ie, designated foaling stalls, pasture, paddock, or combination); type of stall bedding (none, straw, shavings, grass hay, or other) used in foaling stalls, if applicable; whether foal births were attended by farm personnel; percentage (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%) of foal births that were attended; age of foal when first turned out to paddock or pasture (< 1 week, 1 to 2 weeks, 3 to 4 weeks, 5 to 8 weeks, or > 8 weeks); age at which foals were no longer stalled (< 4 weeks, 4 to 8 weeks, 9 to 20 weeks, > 20 weeks, always stalled, or never stalled); practices of comingling or grouping of dam-foal pairs (separate paddocks for each dam-foal pair, groups of 2 to 5 dam-foal pairs, groups of 6 to 10 dam-foal pairs, groups of > 10 dam-foal pairs, or other); determination of dam-foal pair grouping (separate paddocks for each dam-foal pair, or grouped by age of foal, behavioral characteristics, or other means); age of foals at time of weaning (< 12 weeks, 12 to 20 weeks, 21 to 28 weeks, or > 28 weeks); percentage of the dam-foal pairs that were transient (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); percentage of the dam-foal pairs that were resident (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); sources of water for foals (creek or river, pond or lake, water trough, or other); origin of water for foals that drank from a trough (city or county water supply, water well, rain run-off, or other); percentage of foals exposed to other breeding farms during first 6 months of life (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); percentage of foals exposed to other breeding farms that had a history of *R equi* pneumonia (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); whether foals were tested for adequacy of passive transfer of immunoglobulins; percentage of foals tested for adequacy of passive transfer of immunoglobulins (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); administration of plasma to foals to supplement serum immunoglobulin concentration (none, to foals with IgG concentration < 200 mg/dL, to foals with IgG concentration < 400 mg/dL, to foals with IgG concentration < 800 mg/dL, or to all foals regardless of IgG concentration); administration of supplementary colostrum to foals during first 24 hours of life; treatment of foals with other sources of supplemental immunoglobulins (ie, other than plasma or colostrum) and identification of source; administration of *R equi* hyperimmune plasma to foals (number of foals treated, source of hyperimmune plasma, number of times foals were treated, age of foals when treated, dose of hyperimmune plasma administered at each treatment, and route of administration); frequency of administration of anthelmintics to dams (daily, every 2 weeks, every 4 weeks, every 8 weeks, every 12 weeks, every 16 weeks, or never); whether adjustment of parasite control program in mares was performed by use of fecal ova count results; number and brand of anthelmintics administered to dams; frequency of administration of anthelmintics to foals (daily, every 2 weeks, every 4 weeks, every 8 weeks, every 12 weeks, every 16 weeks, or never); whether parasite control program for foals was determined by use of fecal ova counts; number and brand of anthelmintics administered to foals; vaccination of dams against rhinopneumonitis, influenza, *Streptococcus equi* infection, *Clostridium* spp infections, tetanus, viral encephalomyelitis, and equine monocytic ehrlichiosis; vaccination of foals (and if applicable, at what age) against rhinopneumonitis, influenza, *S equi* infection, *Clostridium* spp infections, tetanus, viral encephalomyelitis, and equine monocytic ehrlichiosis; whether removal of manure was practiced; whether removal of manure from paddocks and pastures was practiced; frequency of manure removal from the stalls (never, as occupants changed, weekly, daily, or twice or more daily); frequency of disinfection of stalls (never, annually, as occupants changed, weekly, or daily); type of disinfectant used for stalls (phenolics, quaternary ammonium products, bleach products, or other); type of floors in foals' stalls (dirt, concrete, rubber matting, or other); type of bedding used in foals' stalls (none, shavings, straw, hay, combination of bedding, or other); whether horse manure (fresh or composted, if applicable) was applied as fertilizer on pastures or paddocks; percentage of pasture and paddock area covered with grass versus dirt (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%); veterinarian's subjective assessment of foals' environment (not dusty, mildly dusty, moderately dusty, or severely dusty); measures (other than grass management) taken to decrease dust on the farm; veterinarian's subjective assessment of ventilation in foals' stalls (poorly ventilated, moderately ventilated, or well ventilated); exposure of foals to goats, sheep, cattle, pigs, cats, dogs, chickens, ratites, wild deer, raccoons, opossums, domestic birds, wild birds, or other; and estimated prevalence of respiratory infections (other than *R equi*) in foals on the farm in 1997 (0, 1 to 25, 26 to 50, 51 to 75, or 76 to 100%).

Categories for certain covariates were later consolidated on the basis of results of bivariate analysis (eg, administration of plasma). Consolidation was performed when an apparent classification best characterized the observed association. For example, consolidation of the 4 categories representing foals that received plasma into 1 category enabled us to compare the association of affected farms with administration of plasma to foals. In relation to the lack of treatment with plasma, the other 4 categories added no new information in the magnitude or direction of the estimated association; consequently, the variable levels were collapsed into a single dichotomous factor (plasma administered to any foals vs plasma not administered to any foals).

Statistical analyses—The crude measure of association between a single putative risk factor and a farm being affected was expressed as the relative odds (**odds ratio [OR]**). Bivariate ORs were obtained from conditional logistic regression for matched case-control sets by use of single variables.[38] Confidence limits for the bivariate OR were derived by use of maximum-likelihood estimators.[38] Interval or continuous variables were examined graphically for linearity in the logit. Variables that were not linear in the logit were recoded as categoric variables (either dichotomous or polychotomous outcomes) based on plots of the log-odds. Most often, variables were recoded as categoric variables defined by the median or third quartile value. Nominal variables were treated as a series of indicator variables. Variables associated with a farm being affected with *R equi* at a value of $P < 0.15$ were included in multivariate analysis. Variables included in multivariate analysis were examined for coassociation (collinearity). Collinearity among variables was examined by use of conditional logistic regression to assess the significance of association of 1 variable (eg, assessment of foal serum IgG concentrations) with another (eg, administration of plasma to foals).

Coassociation was also examined by eliminating matching and application of frequency distribution computations and χ^2 tests. The latter approach was considered conservative because the net effect of eliminating matching should have been to create bias in the results toward unity (ie, lack of association).

Because of the large number of covariates examined, the modest number of farms studied, and considerable collinearity among covariates, multivariate models were constructed for variables that related to farm and environmental management and preventative health practices. By use of multiple conditional logistic regression[38] models, estimates were obtained of the magnitude and direction of the association of development of *R equi* pneumonia in foals on a farm with factors selected from bivariate analyses; these models were also used to obtain estimates for single variables adjusted for the effects of other variables associated with an affected farm. For multivariate analysis, variables were selected for inclusion in models by use of a combination of forward selection and backward elimination procedures. The stepwise option of the statistical software[a] was used for analyses, beginning with a null model and using a likelihood ratio χ^2 test; a value of $P < 0.10$ was needed for a variable to be entered (selection steps) in the model, and $P > 0.15$ was used as the cutoff for removal (backward elimination steps).[38] Variables were selected for inclusion in the final model by use of a method to test the joint significance of the model and on the basis of biological plausibility. The method for joint significance entailed examining the likelihood ratio χ^2 test statistic of the model at each step compared with the immediately preceding step; a significance level of $P < 0.10$ was used.[38] Variables selected for inclusion in a final multivariate model were considered factors that best predicted a farm would be affected by *R equi*. All possible bivariate interactions among main effects variables significantly associated with a farm being affected with *R equi* were examined. Conditional logistic regression analyses were conducted with commercially available statistical software.[a] Goodness-of-fit was assessed graphically by plotting the deviance residuals for the conditional logistic regression analysis versus the linear predictors for individual observations. Case-control sets for individuals that appeared to have extreme values on visual examination of these plots were excluded from the analyses to evaluate their influence on estimated OR; if they appeared to influence results, these case-control sets were considered outlying data and were eliminated from the modeling procedure.

Results

Participating veterinarians—Of 82 veterinarians that originally agreed to participate, 32 provided complete data from 1 matched set of control and affected farms.

Parturition on farm premises or elsewhere—Thirty-one of the 32 affected farms (96.9%) had 1 or more foals delivered on the farm premises; 30 of the 32 control farms (93.8%) had 1 or more foals delivered on site. There was no significant difference between control and affected farms as to whether any mares delivered foals on the premises. Of the affected farms, 3 (9.4%) transferred certain mares to other breeding farms for parturition; similarly, 3 (9.4%) control farms transferred certain mares to another breeding farm for parturition.

Location of foal births on the farm—Categoric data were recorded from 31 affected farms and 32 control farms relating to location on the farm where foals were born. Specifically designated foaling stalls were used for foaling on 15 (48.4%) affected and 15 (46.9%) control farms. Foals were born in paddocks on 6 (19.4%) affected and 5 (15.6%) control farms. Foals were born in a pasture on 4 (12.9%) affected and 8 (25%) control farms. Combinations of stalls, paddocks, and pasture were the sites of foaling on 6 (19.5%) affected and 4 (12.5%) control farms. There was no significant association between site of foal birth and risk for development of *R equi* pneumonia. When this variable was further categorized (ie, foaling indoors vs outdoors), there still was no significant association with development of *R equi* pneumonia in foals.

For farms that used specifically designated foaling stalls, the type of stall bedding was recorded. Wood shavings were the most frequent type of bedding used for both the affected (11/26 [42.3%]) and control (10/21 [47.6%]) farms. There was no significant association between type of foaling stall bedding and risk for development of *R equi* pneumonia in foals.

Of the affected farms, 24 (75%) had personnel in attendance for 76 to 100% of foal births; of the control farms, 17 (53%) recorded that 76 to 100% of foal births were attended. When this variable was further categorized into ≤ 25 versus > 25% of foal births, affected farms were significantly more likely to have personnel observe and attend > 25% of foal births (**Table 1**).

Age of foals when first turned out to pasture or paddock—Information about age of foals when first turned out to pasture or paddock was recorded from 31 pairs of control and affected farms. When this variable was further categorized (< 3 vs ≥ 3 weeks of age), foals from 24 (77.4%) affected and 30 (96.8%) control farms were turned out at < 3 weeks of age. These data were not analyzed statistically because of complete separation (ie, a zero cell in the table for this bivariate comparison).

Categoric data were collected for 64 farms regarding age at which foals were no longer stalled. There was no significant association between age at which foals were no longer stalled and their risk for development of *R equi* pneumonia.

Comingling of dam-foal pairs—There was no significant difference between control and affected farms in the proportion of dam-foal pairs that were comingled in groups of 1, 2 to 5, 6 to 10, and > 10 dam-foal pairs. When these data were further categorized (housed in groups of 2 to 5 dam-foal pairs vs housed in groups of other sizes), there was a significant difference between affected and control farms (Table 1); control farms were more likely to house animals in groups of 2 to 5 dam-foal pairs than were affected farms. The basis for determination of dam-foal pair comingling was recorded for 30 affected farms and 29 control farms; there was no significant association with *R equi* pneumonia in foals.

Age of foals when weaned—When weaning age was examined categorically (≤ 5 vs > 5 months), affected farms were significantly more likely to wean foals at ≤ 5 months than were control farms (Table 1).

Water source for foals—Information was recorded from all 64 farms regarding sources of water for foals.

Table 1—Comparison of variables between 32 farms on which foals developed *Rhodococcus equi* pneumonia and 32 control farms

	R equi	Control			
Variable	**No. (%)**	**No. (%)**	**Odds ratio**	**95% CI**	***P* value**
Foal births attended or observed					
≤ 25% of foal births	5 (15.6%)	10 (31.3%)	1	NA	NA
> 25% of foal births	27 (84.4%)	22 (68.8%)	3.45	0.72, 16.67	0.118
No. of dam-foal pairs comingled					
2-5 dam-foal pairs	11 (34.4%)	17 (54.8%)*	1	NA	NA
Other categories	21 (65.6%)	14 (45.2%)*	4.00	0.85, 18.87	0.08
Age of foals at time of weaning					
> 5 months	14 (45.2%)*	19 (59.4%)	1	NA	NA
≤ 5 months	17 (54.8%)*	13 (40.6%)	5.88	0.72, 50.00	0.097
Foals exposed to other breeding farms during first 6 months of life					
0%	4 (12.5%)	8 (25.0%)	1	NA	NA
> 0%	28 (87.5%)	24 (75.0%)	3.00	0.61, 14.93	0.178
Testing of serum IgG concentration					
No	8 (25.0%)	14 (45.2%)*	1	NA	NA
Yes	24 (75.0%)	17 (54.8%)*	4.00	0.85, 18.84	0.079
Foals tested for serum IgG concentration					
≤ 25%	6 (20.7%)	16 (50.0%)	1	NA	NA
> 25%	23 (79.3%)	16 (50.0%)	10.00	1.28, 76.92	0.028
Administration of plasma to foals to supplement serum immunoglobulin concentration					
No	13 (40.6%)	21 (70.0%)	1	NA	NA
Yes	19 (59.4%)	9 (30.0%)	10.00	1.28, 76.92	0.028
Administration of products other than plasma and colostrum to foals to supplement serum immunoglobulin concentration					
No	16 (50.0%)	24 (75.0%)	1	NA	NA
Yes	16 (50.0%)	8 (25.0%)	5.00	1.10, 22.73	0.038
Administration of *R equi* hyperimmune plasma for prophylaxis against *R equi* pneumonia					
No	20 (62.5%)	31 (96.9%)	ND	ND	ND
Yes	12 (37.5%)	1 (3.1%)	ND	ND	ND
Frequency of deworming of dams					
≥ 12 weeks	10 (33.3%)	17 (56.7%)	1	NA	NA
< 12 weeks	20 (66.7%)	13 (43.3%)	4.00	0.85, 18.87	0.079
Number of anthelmintics used in dam parasite control program					
Only 1	5 (16.7%)	11 (36.7%)	1	NA	NA
> 1	25 (83.3%)	19 (63.3%)	4.00	0.85, 18.87	0.079
Number of anthelmintics used in foal parasite control program					
Only 1	5 (17.2%)	11 (36.7%)	1	NA	NA
> 1	24 (82.8%)	19 (63.3%)	5.99	0.72, 50.00	0.097
Vaccination of dams against *Streptococcus equi* infection					
No	8 (25.8%)	15 (50.0%)	1	NA	NA
Yes	23 (74.2%)	15 (50.0%)	4.00	0.85, 18.84	0.079
Vaccination of foals against *S equi infection*					
No	8 (26.7%)	13 (44.8%)	1	NA	NA
Yes	22 (73.3%)	16 (55.2%)	3.50	0.73, 16.85	0.1182
Prevalence of respiratory tract infections (other than *R equi*) in foals					
0%	3 (9.4%)	10 (31.3%)	1	NA	NA
> 0%	29 (90.6%)	22 (68.7%)	8.00	1.00, 62.50	0.050
Flooring in foals' stalls					
Concrete or rubber mats	11 (36.7%)	15 (51.7%)	1	NA	NA
Dirt	19 (63.3%)	14 (48.3%)	2.67	0.71, 10.05	0.147
Exposure of foals to cattle					
Yes	21 (65.6%)	16 (50.0%)	1	NA	NA
No	11 (34.4%)	16 (50.0%)	0.29	0.06, 1.38	0.1182

*Data were available from 29 to 32 farms in each group.
CI = Confidence interval. NA = Not applicable (referent category). ND = Not done because of complete separation (zero cell in table).

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A water trough was the source of water for 27 (84.4%) affected farms and 28 (87.5%) control farms; this difference was not significant. Of the 27 affected and 28 control farms where water troughs were used, there was no significant difference in the origin of water between affected and control farms.

Percentage of foals that were exposed to other breeding farms during first 6 months of life— Information was recorded for all 64 farms regarding the percentage of foals that were exposed to other breeding farms during the first 6 months of life. When this variable was further categorized (0 vs > 0%), more affected farms had > 0% of their foals exposed to other breeding farms than did control farms; however, this difference was not significant. Information was recorded from 18 affected farms and 19 control farms regarding the percentage of foals exposed to other farms with a history of *R equi* pneumonia. When this variable was further categorized (0 vs > 0%), affected farms (13/18) were not more likely than control farms (7/19) to have foals exposed to other farms that had a history of *R equi* pneumonia.

Assessment of passive immunity—Affected farms were significantly more likely to test foals for adequacy of passive transfer of immunoglobulins than were control farms (**Table 2**). Percentages of foals in which serum IgG concentration was assessed were examined categorically (≤ 25 vs > 25%); affected farms were more likely to test > 25% of their foals than were control farms (Table 1).

Administration of plasma to supplement IgG—No foals received supplements of plasma on 13 (40.6%) affected farms, compared with 21 (70.0%) control farms. Plasma was administered as a supplement to foals with serum IgG concentration < 200 mg/dL for 2 (6.3%) affected farms and 1 (3.3%) control farm. Supplements of plasma were given to foals with serum IgG concentration < 400 mg/dL for 9 (28.1%) farms and 7 (23.3%) control farms. Foals with serum IgG concentration < 800 mg/dL were administered plasma supplements on 5 (15.6%) affected farms and 1 (3.3%) control farm. All foals, regardless of serum IgG concentration, received supplementation with plasma on 3 (9.4%) affected and 0 control farms. This variable was examined categorically (plasma administered to at least 1 foal vs plasma administered to no foals); affected farms were 10 times as likely to administer plasma to foals for supplementation of serum IgG concentration as were control farms (Table 1).

Administration of colostrum or other products to supplement serum IgG concentration—Information regarding administration of supplementary colostrum to foals < 24 hours old was recorded for all 64 farms. Of 32 affected farms, 11 (34.4%) administered supplementary colostrum to foals, as did 9 of 32 (28.1%) control farms. There was no significant difference between the number of control and affected farms that conducted this practice.

Seven (21.9%) affected and 4 (12.5%) control farms administered commercially available concentrated serum[b] to foals. Three (9.4%) affected farms and 1 (3.1%) control farm treated foals with commercially available *Salmonella* serovar Typhimurium antiserum.[c] Five (15.6%) affected and 2 (6.3%) control farms administered *Escherichia coli* antiserum[d] to foals. When this variable was further categorized (no supplementation other than colostrum or plasma vs supplementation to some foals), affected farms were significantly more likely to supplement foals' serum IgG concentrations with sources of IgG other than plasma or colostrum than were control farms (Table 1).

Administration of hyperimmune *R equi* plasma— Affected farms were more likely to administer *R equi* hyperimmune plasma to foals than were control farms (Table 1). The median number of foals on affected farms that received *R equi* hyperimmune plasma was 17 (range, 0 to 125 foals). One control farm administered *R equi* hyperimmune plasma to 10 foals. One source of hyperimmune plasma[e] was used by all 13 farms that administered hyperimmune plasma; all treatments were given IV. On the 13 farms, median number of treatments with hyperimmune plasma per foal was 1 (range, 1 to 3 treatments). Median age of foals when hyperimmune plasma was first administered was 1 week (range, 0 to 12 weeks). Median quantity of hyperimmune plasma administered IV at each treatment was 950 mL (range, 500 to 1,000 mL).

Parasite control for dams and foals—Frequency of deworming the dams was examined categorically (< 12 vs ≥ 12 weeks); affected farms were more likely to deworm the dams at intervals of < 12 weeks than were control farms (Table 1). Adjustment of parasite control program in dams by use of fecal ova count results was noted for 31 pairs of affected and control farms. Of 31 affected farms, 2 (6.5%) applied fecal ova count results to the implementation of parasite control programs in dams, compared with 1 of 31 (3.2%) control farms. There were no differences in the proportions of farms that used results of fecal ova counts to appropriately modify the parasite control programs for dams. The number of anthelmintics used in the dams' parasite control program was examined categorically (1 vs > 1 anthelmintic); affected farms were significantly more likely to use > 1 anthelmintic in the dams' parasite control program (Table 1).

Information was recorded from 29 affected and 31 control farms regarding the frequency of deworming of the foals. Twelve (41.4%) affected and 12 (38.7%) control farms dewormed foals at 4-week intervals. Twelve (41.4%) affected and 13 (41.9%) control farms dewormed foals at 8-week intervals. There was no significant difference between control and affected farms in frequency of deworming foals. Of 32 affected farms, 2 (6.3%) used results of fecal ova counts to customize

Table 2—Variables significantly ($P < 0.05$) associated with the development of *R equi* pneumonia in foals on 32 equine breeding farms

Variable	Odds ratio	95% CI	*P* value
Dirt floors present in stalls used in foal husbandry	3.92	0.77, 19.94	0.100
Administration of plasma to foals to supplement serum IgG concentrations	12.23	1.34, 111.52	0.026

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foal parasite control programs, compared with 0 (0%) control farms; this difference was not significant. The number of anthelmintics used in a foal parasite control program was examined categorically (1 vs > 1 anthelmintic); affected farms were significantly more likely to use > 1 anthelmintic.

Vaccination of dams and foals—Vaccination history was recorded for dams (31 affected and 30 control farms) and foals (30 affected and 29 control farms). There were no significant differences between control and affected farms with regard to vaccination of dams or foals against rhinopneumonitis, influenza, *Clostridium* spp infection, tetanus, viral encephalomyelitis, equine monocytic ehrlichiosis, or other disorders. Affected farms were significantly more likely to vaccinate dams and foals against *S equi* infection than were control farms (Table 1). There were no differences between control and affected farms in regard to age at which foals were first vaccinated against any of these diseases.

Prevalence of respiratory infections (other than *R equi*) among foals—The prevalence of respiratory infections (other than *R equi*) among foals was 0% for 3 (9.4%) affected and 10 (31.3%) control farms; 1 to 10% for 13 (40.6%) affected and 10 (31.3%) control farms; 11 to 25% for 5 (15.6%) affected and 5 (15.6%) control farms; 26 to 50% for 7 (21.9%) affected and 3 (9.4%) control farms; 51 to 75% for 2 (6.3%) affected and 1 (3.1%) control farms; and 76 to 100% for 2 (6.3%) affected and 3 (9.4%) control farms. When this variable was further categorized (0 vs > 0%), affected farms were significantly more likely than control farms to have > 0% of their foals affected with other respiratory infections (Table 1).

Other farm management factors—Information was recorded for 31 affected and 32 control farms regarding whether the farm had a program for removal of horse manure. Sixteen (51.6%) affected and 17 (53.1%) control farms practiced manure removal; this difference was not significant. Ten (32.3%) affected and 7 (21.9%) control farms reported that manure was removed routinely from paddocks and pastures; this difference was not significant. Frequency of manure removal from foal stalls was not significantly different between 30 affected and 26 control farms. There was no significant difference between farm groups in frequency of disinfection of foal stalls or the type of disinfectant used.

The type of floor in the stalls used for housing foals was examined categorically (dirt floor vs other flooring); affected farms were more likely to have a dirt floor in foal stalls than were control farms (Table 1). Type of bedding used on the floors of foal stalls was not significantly different between control and affected farms.

The number of farms that reported use of horse manure as fertilizer on pastures and paddocks was not significantly different between affected farms (13/31 [41.9%]) and control farms (9/30 [30.0%]). Four of 13 affected farms and 3 of 9 control farms reported that horse manure was composted before application to paddocks or pastures; this difference was not significant.

For all 64 farms, veterinarians recorded their subjective assessment of the amount of dust in the foals' environments. Foals' environments were classified as moderately or severely dusty on 15 (46.9%) affected farms, compared with 11 (34.4%) control farms (no significant difference). Percentages of pastures and paddocks that were grass-covered (not dirt) were not significantly different. Three (9.4%) affected and 6 (18.8%) control farms used other measures (in addition to grass management) to reduce dust on the farm; this difference was not significant. The quality of ventilation in the stalls was assessed as poor for 2 of 31 (6.5%) affected and 2 of 30 (6.7%) control farms; average for 14 (45.2%) affected and 12 (40.0%) control farms; and excellent for 15 (48.4%) affected and 16 (53.3%) control farms; these differences in the distribution of this variable between control and affected farms were not significant.

Exposure of foals to other species of animals—Exposure of foals to goats, sheep, pigs, cats, dogs, chickens, ratites, wild deer, raccoons, opossums, domestic birds, wild birds, or other animals did not differ significantly between control and affected farms. Foals were significantly less likely to be exposed to cattle on affected than control farms (Table 1).

Multivariate modelling—Covariates used in a multiple variable model-building strategy included whether > 25% of foal births were observed and attended by farm personnel; age of foals at time of weaning (> 5 vs ≤ 5 months); dam-foal pairs comingled in groups of 2 to 5 versus other groupings; whether foals were tested for adequacy of passive transfer of IgG; whether > 25% of foals were tested for adequacy of passive transfer of IgG; whether plasma was administered to foals to supplement serum IgG concentration; whether any product other than colostrum or plasma was administered to foals to supplement serum IgG concentration; whether foals received hyperimmune *R equi* plasma as prophylaxis against *R equi* pneumonia; whether mares were vaccinated against *S equi* infection; whether foals were vaccinated against *S equi* infection; whether frequency of deworming of dams was < 12 weeks; whether > 1 anthelmintic was used in the dams' parasite control program; whether > 1 anthelmintic was used in the foals' parasite control program; whether foals at the farm developed respiratory tract infections other than *R equi* pneumonia; whether foals' stalls had dirt floors; and whether foals were exposed to cattle at the farm.

The final multivariate model included the variable administration of plasma to foals and whether foals' stalls had dirt floors (Table 2). Affected farm personnel were approximately 12 times as likely to administer plasma to foals to supplement serum IgG concentration as were control farm personnel. Affected farms were approximately 4 times as likely to have dirt floors in stalls used for housing foals as were control farms. No significant bivariate interactions were observed, and no parameters appeared to include extreme values, as judged by visual examination of goodness-of-fit plots.

Discussion

Numerous practitioners participated in this study[37]; thus, we selected diagnostic criteria that were suitable for veterinarians with various diagnostic preferences,

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equipment, and levels of expertise and experience. Our study[37] had limitations because of its design. For data such as ventilation, dustiness of the environment, and percentage of the pastures and paddocks that were grass, veterinarians were required to make subjective or semiquantitative assessments; the accuracy and reliability of these data are unknown. Despite the limitations of this study, we believe the results provide veterinarians and horse owners with useful information regarding management and preventative health care practices associated with *R equi* pneumonia in foals.

Some variables that were significantly associated with *R equi* pneumonia in the bivariate analysis but were not retained in the multivariate model may be important risk factors for *R equi* pneumonia. For example, the percentage of foals tested for IgG concentration was significantly associated with whether plasma was administered to foals to supplement IgG concentrations. Consequently, both variables were likely important, although multivariate models using administration of plasma were statistically superior.

Preventative health care programs of affected and control farms were different in numerous ways. In general, results of this study indicated that pneumonia caused by *R equi* was not associated with poor preventative health practices. In fact, several recommended management practices appeared to be associated with increased risk for development of *R equi* pneumonia. It is possible that farms with better management practices observe foals more closely and are, therefore, more likely to detect foals with *R equi* pneumonia; however, the progressive and often fatal outcome of undetected respiratory disease caused by *R equi* leads us to believe that this explanation is unlikely. In bivariate analyses, affected farms were more likely to attend > 25% of foal births than were control farms. This factor was probably not biologically important in the development of *R equi* pneumonia on these sites, but may indicate that breeding farms with larger populations of horses[37] were more likely to have personnel constantly available to observe and attend many of the foal births. Affected farms were more likely to wean their foals at ≤ 5 months of age than control farms; it is unlikely that this factor was important in the pathogenesis of *R equi* pneumonia, as most affected foals develop signs of the disease prior to 5 months of age. This finding may reflect a management practice more common at farms with larger populations.[37]

Affected farms were more likely to test foals for adequacy of passive transfer of IgG. Similarly, affected farms were approximately 10 times as likely to administer plasma IV to foals to supplement serum IgG concentrations. This variable remained significant in the multivariate analysis. Hypogammaglobulinemia, or **failure of passive transfer (FPT)** of immunoglobulins, is the most common immunologic disorder of foals. Generally, FPT develops because the colostrum is of poor quality or insufficient quantity, intake by the foal is inadequate, or the ability to absorb immunoglobulins via the intestinal tract is compromised.[39-46] Although the clinical importance of FPT has been questioned,[41] it has long been considered a common predisposing factor for infectious disease in young foals. Numerous studies[42-46] reveal an association between FPT and septicemia and other infectious disorders, and in 1 prospective study[1] it is suggested that farms that routinely assess foals for FPT have a lower prevalence of septicemia and pneumonia. In another report,[39] it is stated that the passive immune status of foals had no significant association with development of *R equi* pneumonia in 19 affected foals (17 affected foals had IgG concentrations > 800 mg/dL, 1 affected foal had IgG concentration > 400 mg/dL, and serum IgG concentration was not determined for the 1 remaining affected foal). Measurement of foal serum IgG concentration during the first 24 hours of life is a commonly used method to assess adequacy of passive maternal immunity. This assessment is performed routinely on many farms, and plasma is administered to foals that have serum IgG concentrations below a certain cutoff point (ie, < 400 mg of IgG/dL or < 800 mg of IgG/dL). Although we did not compare IgG concentrations of individual foals in this study, our data indicated that farm management programs aimed at providing adequate foal serum IgG concentration did not decrease the risk of *R equi* pneumonia. In fact, the disease was more common on farms that quantified foal serum IgG concentration and treated selected foals with supplements of plasma administered IV. Similarly, affected farms were more likely to administer products other than plasma or colostrum to foals in an attempt to enhance serum IgG concentration.

Affected farms were more likely to administer *R equi* hyperimmune plasma to foals than were control farms. Our interpretation of this finding was that it was not a causal effect but illustrated that farms with a history of *R equi* foal pneumonia were more likely to administer hyperimmune plasma prophylactically in an attempt to minimize the incidence and severity of this disease. The immunoprophylactic effect of hyperimmune plasma has been proven under experimental[17] and natural farm conditions[18-20]; however, in 1 report[21] it is suggested that hyperimmune plasma is not effective at decreasing the incidence of *R equi* pneumonia. The mechanism through which hyperimmune plasma protects against disease remains unknown.[5,17-21] The dosage of plasma and the age at time of administration required to provide optimal protection are also unknown.[4,5,20]

In previous reports,[24,36,47] it is suggested that initiation of sound parasite control and vaccination programs may help decrease risk for *R equi* foal pneumonia. It is suggested that tissue damage and general debilitating effects associated with viral infections and migrating parasites would likely increase a foal's susceptibility to *R equi*. Also, it has been suggested that *R equi* may be introduced into a foal's lungs via migrating parasites, and 1 study[47] indicates an association between *R equi* outbreaks and *Strongylus westeri* infection. More recently, evidence has been obtained that supports inhalation and ingestion as the major routes of infection,[12-14] and our findings suggested that intensive parasite control programs were not effective at decreasing the risk of *R equi* pneumonia. Affected farms were more likely to use > 1 anthelmintic in parasite control programs of dams and foals and were more likely to deworm the dams at intervals < 12 weeks than were control farms.

Affected farms were more likely to vaccinate their dams and foals against *S equi* infection than were control farms. The importance of this finding is unknown. The larger population of horses and the higher proportion of transient mares and foals on affected farms[37] may have enhanced the probability of horses being exposed to *S equi*. Thus, more intensive management practices to decrease the incidence and severity of *S equi* infections were likely to be performed on affected farms. We do not believe this factor to be biologically important in the pathogenesis of *R equi* pneumonia, as most foals would likely be vaccinated against *S equi* at an age greater than that at which they are most susceptible to *R equi* infection[14,48]; it is also difficult to establish a biologically valid causal association between vaccination against *S equi* infection and development of *R equi* pneumonia.

In our study, affected farms were significantly more likely to have foals affected with respiratory infections other than *R equi* than were control farms. It is unknown whether this finding reflected undiagnosed cases of *R equi* foal pneumonia, higher prevalence of immunologic disorders in foals, or simply an increased risk for infectious respiratory tract disease associated with the large horse populations and increased proportion of transient mares and foals on affected farms.[37] A previous study[20] also revealed that farms on which *R equi* pneumonia is endemic have significantly greater prevalence of foal respiratory disease than that of other farms.

There was no significant difference between affected and control farms regarding the implementation of a program for manure disposal from the stalls, paddocks, or pastures. Similarly, there was no significant difference in the frequency of manure removal from those areas. Horse manure is thought to contribute to environmental contamination with *R equi* because it contains volatile fatty acids that enhance the growth of *R equi* in the soil environment[27] and is also a source of bacterial contamination of the environment.[2,31,33] Removal of horse manure from the foaling stalls, paddocks, and pastures could theoretically decrease environmental contamination and reduce exposure of susceptible foals to *R equi*[4,5]; however, the manure removal programs used by farms in this study did not significantly alter the risk for development of *R equi* pneumonia in foals.

Our analyses detected no significant difference between control and affected farms in whether horse manure was spread on the pastures as fertilizer, nor was there a significant difference in whether horse manure was composted prior to its use on pastures. Spreading feces containing virulent *R equi* directly on pastures could increase contamination of the environment and subsequent foal exposure. Composting manure before spreading it on pastures has been recommended, although data to support this are lacking. The impact of manure disposal on the prevalence of *R equi* pneumonia in foals has not been addressed.

Affected farms were nearly 4 times as likely as control farms to have dirt floors in stalls used for housing foals. There was no significant difference in the type of bedding used in the stalls. *Rhodococcus equi* can multiply and flourish in soil when environmental conditions are suitable, and large numbers of *R equi* are isolated from the soil surface[28,30]; therefore, foals housed in stalls with dirt floors may be exposed to higher concentrations of microorganisms. On most of the farms of this report, foals were housed in stalls continuously during the first few days to weeks of life, after which they were housed in stalls for lesser periods. It is possible that dirt floors in the stalls allow the bacteria to multiply in the environment; thus, foals are exposed to greater numbers of virulent *R equi* early in life. Farms that use concrete or rubber-matted stall floors may have less environmental contamination and proliferation of *R equi*; thus, foals may be exposed to a lesser bacterial challenge. Based on experimental and epidemiologic evidence, foals are more susceptible to infection with *R equi* during the first few weeks of life, and most spontaneous infections occur during this period.[15,48] Exposure of foals to high concentrations of the microorganism via stall confinement during the first few days of life would likely increase the probability of disease. If this finding is validated in future studies, farms could consider using alternative non-dirt stall floors to reduce environmental challenge to foals and possibly decrease the subsequent risk of foals developing *R equi* pneumonia. Alteration of the soil environment in the stall may also decrease exposure of foals to the bacteria[5,47] and reduce the incidence of this disease.

Our data revealed no significant difference between control and affected farms in subjective assessments of environmental dust and adequacy of ventilation. Also, the proportion of the pastures and paddocks that was grass covered was not significantly different between control and affected farms. It was beyond the scope of this study to quantitatively assess the amount of dust or the quality of ventilation in the foals' environment. A dusty environment has been associated anecdotally with *R equi* infections.[4,5,24] The microorganism can be cultured from the air; it is reported that the number of airborne *R equi* bacteria increases on dry and windy days,[27] and such weather conditions are associated with increased incidence of disease.[35,36] It has been stated empirically that poor ventilation, dusty stables, and housing of foals on bare, dusty paddocks are implicated in increased risk for development of *R equi* pneumonia.[4,10,22-24,35] Grass planting in areas that contain bare soil and minimal exposure of foals to bare dirt areas has been recommended.[4] Irrigation of the paddocks to minimize dust in the atmosphere and reduce aerosolization of *R equi* has also been suggested.[4,10] Further investigation is needed to critically evaluate the effects of such environmental management procedures on the prevalence of *R equi* infections.

In the bivariate analyses, farms that had foals in contact with cattle were at significantly lower risk for development of *R equi* pneumonia. The importance of this finding in the pathogenesis of the disease is unknown, but it appears to be an unimportant risk factor. *Rhodococcus equi* has been isolated from 40% (12/30)[49]

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and 26% (101/390)[50] of fecal samples from healthy cattle and from 52 (100%) soil samples obtained at the feeding area of cattle.[50] It seems possible that fecal material from cattle may contribute to contamination of the soil with *R equi* and, thus, increase risk for development of *R equi* pneumonia in foals; however, our data suggested that exposure to cattle did not increase this risk. It is plausible that large-population horse breeding farms[37] that have foals affected with *R equi* pneumonia are more specialized horse farms and are, therefore, less likely to have cattle on the premises than the smaller control farms in our study. Exposure to domestic and wild animals other than cattle did not appear to affect the risk for development of *R equi* pneumonia in foals.

This study provided evidence of specific farm management practices that are associated with increased risk for development of *R equi* pneumonia in foals. Farms that house their foals in stalls with dirt floors appear to be at high risk although, in general, development of *R equi* pneumonia in foals was not associated with a lack of preventative health care practices.

[a]SAS/STAT, SAS Institute Inc, Cary, NC.
[b]Seramune, oral equine IgG, Sera Inc, Shawnee Mission, Kan.
[c]Endoserum, *Salmonella* Typhimurium antibody (equine origin), IMMVAC Inc, Columbia, Miss.
[d]Equine Coli Endotox, *Escherichia coli* antiserum, Grand Laboratories Inc, Larchwood, Iowa.
[e]Polymune R, Veterinary Dynamics Inc, Templeton, Calif.

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