Foal-related risk factors associated with development of *Rhodococcus equi* pneumonia on farms with endemic infection

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Objective—To identify foal-related risk factors associated with development of *Rhodococcus equi* pneumonia among foals on farms with endemic *R equi* infection.

Design—Prospective case-control study.

Animals—220 foals at 2 equine breeding farms in Texas during a 2-year period.

Procedure—Information collected for each dam included age, time housed on the farm prior to parturition, whether there were any peripartum illnesses, parity, and health of previous foals. Information collected for each foal included breed, sex, gestational age, month and year of birth, location of birth, type of flooring and bedding in stall, postpartum management and preventive health care, passive immunity status, supplementation of immunoglobulins, exposure to other farms or foals affected with *R equi* pneumonia, stall and pasture exposure, commingling with other mare-foal pairs, age at weaning, and whether the foal developed *R equi* pneumonia.

Results—32 of the 220 (15%) foals developed *R equi* pneumonia, of which 4 (13%) died. Foals at 1 of the 2 farms and foals born during the second year of the study were more likely to develop *R equi* pneumonia. Foal-related factors that were examined were not significantly associated with risk of *R equi* pneumonia in multivariate analyses.

Conclusions and Clinical Relevance—Results suggest that there are farm- and year-related effects on the risk that foals will develop *R equi* pneumonia. Other foal-related factors significantly associated with *R equi* pneumonia were not identified. (*J Am Vet Med Assoc* 2003;223:1791–1799)

Rhodococcus equi infection is considered the most common cause of severe pneumonia in foals[1-4] and has a substantial impact on equine breeding farms because of its high prevalence and case fatality rates.[2-5] However, despite considerable advancements in the understanding of *R equi* foal pneumonia in the past few years, efforts to control and prevent infection remain elusive. Identification of farm- and foal-related risk factors associated with *R equi* pneumonia would enhance the understanding of factors that affect the probability that foals will develop the disease; however, appropriately designed epidemiologic studies of risk factors associated with disease acquisition and transmission have been limited. Previously, we reported 2 studies[6,7] that examined farm-related risk factors associated with *R equi* infection. In a study[6] of 64 equine breeding farms in Texas, we found that farms with a large acreage, a large population of mares and foals, a high density of foals, and a transient population of mares and foals were more likely to have foals affected with *R equi*. We also found that *R equi* was not associated with poor farm management or a lack of attention to preventive health care practices.[7] In fact, farms affected with *R equi* pneumonia were generally better managed and provided more recommended preventive health care practices than did control farms.[7] Other epidemiologic studies[8-21] of *R equi* pneumonia have also been reported; however, few of these studies have addressed foal-related factors that may predispose foals to develop *R equi* pneumonia.

On farms on which *R equi* infection is endemic, some foals develop *R equi* pneumonia and others do not, yet presumably all foals on the farm are exposed to the organism in a reasonably similar manner. It is not known what is different about those foals that develop disease, compared with those that do not. Information about foal-related risk factors may allow farms on which the disease is endemic to decrease the prevalence and economic impact of the disease. Furthermore, identification of foal-related risk factors on such farms would allow for more focused and likely more effective prophylactic programs (it is more practical and cost-effective to administer hyperimmune plasma to high-risk foals rather than to all foals on the farm) and more focused and practical programs for early detection of disease (it is more practical to perform screening tests on high-risk foals than on all foals on the farm). Thus, the purpose of the study reported here was to identify foal-related risk factors associated with development of *R equi* pneumonia among foals on farms in Texas with endemic *R equi* infection.

Materials and Methods

Participating breeding farms—Participating farms were selected from those that had previously participated in studies[6,7] to determine farm-related risk factors associated with *R equi* pneumonia. Participating farms met the following criteria for inclusion in the study: availability of at least 50 foals/y on the farm, a history of endemic *R equi* foal pneumonia with

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Supported by the Link Equine Research Endowment and USDA Animal Health-Formula Funds, College of Veterinary Medicine, Texas A&M University, and the American Quarter Horse Association.

The authors thank Erin Brown and Wade Friedeck for technical assistance.

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at least 20% of the foal population affected, ability and willingness to accurately collect morbidity and mortality data for foals during the first 6 months of life, and availability of veterinary services for proper diagnosis and treatment of *R equi* pneumonia. Farms were solicited to participate through telephone calls and visits. One of the investigators (MKC) screened all farms to determine whether they met the criteria for inclusion in the study.

Data collection—Veterinarians who provide primary veterinary services for participating farms were requested to complete data collection forms for each foal on the farm during the years 1999 and 2000. Veterinarians were encouraged to collaborate as needed with farm managers and personnel to ensure accuracy of responses. A foal was considered to have *R equi* pneumonia if it was between 3 weeks and 6 months old, it had clinical signs of pneumonia (eg, tachypnea, fever, nasal discharge, and cough), and *R equi* was isolated from a tracheobronchial aspirate or postmortem lung specimen or if the foal was between 3 weeks and 6 months old, it had clinical signs of pneumonia, and at least 2 of the following were identified: multifocal pulmonary opacities on thoracic radiographs, ultrasonographic evidence of pulmonary abscesses, or gram-positive intracellular coccobacilli evident during cytologic evaluation of transtracheal wash specimens. A foal and its dam were defined as a mare-foal pair.

Information obtained for mares—Information collected for the dam of each foal included name, age, duration of gestation, time housed on the farm prior to parturition (< 1 week, 1 to 4 weeks, 4 to 12 weeks, 12 to 52 weeks, or > 52 weeks), whether the dam was sick during the last 3 months of gestation, whether the dam was sick during the first 3 months of lactation, parity, whether the dam had previously had a foal with *R equi* pneumonia, number of previous foals for which medical information was available, and, of the previous foals for which medical information was available, number of previous foals with *R equi* pneumonia.

Information obtained for foals—Information collected for each foal included the date the data form was completed, name of the attending veterinarian, name of the farm, year of birth, foal identification number, breed, and sex.

Information collected regarding each foal's birth included whether the foal was born on the farm; location on the farm where the foal was born (ie, specifically designated foaling stalls, paddock, pasture, or other); for foals born in a stall, type of floor in the stall (ie, dirt, sand, concrete, rubber mats, or other) and type of stall bedding (ie, none, straw, shavings, grass hay, shavings and grass hay, or other); whether the birth was attended by farm personnel; whether the mare or foal had medical problems during delivery; and whether the foal was treated with antimicrobials during the first week of life.

Information collected regarding passive immune status of each foal included whether the foal stood and suckled within 3 hours after birth; whether the foal received colostrum (either through suckling or via nasogastric intubation) within the first 3 hours after birth; specific gravity of the dam's colostrum prior to suckling; whether the foal was tested for adequacy of passive transfer of immunoglobulins; age at which the foal was tested for adequacy of passive transfer of immunoglobulins (ie, < 12 hours, 12 to 24 hours, 25 to 36 hours, or other); type of assay used for measuring foal serum IgG concentration; foal's serum IgG concentration; whether the foal was given supplemental frozen colostrum via a nasogastric tube, frozen colostrum via a bottle, dam's colostrum via a nasogastric tube, or dam's colostrum via a bottle; whether the foal was given non-*R equi* plasma IV, ***R equi* hyperimmune plasma (REHP)** IV, concentrated equine serum IgG,[a] bovine colostrum, *Salmonella* Typhimurium antiserum,[b] *Escherichia coli* antiserum,[c] or other immune supplements; and, if the foal received REHP, the source of plasma, number of treatments, ages at which plasma was administered, amount of REHP administered at each treatment, and route of administration.

For foals not born on the farm, information collected regarding management of each foal included age at which the foal arrived; whether the foal was shipped off the farm during the first 6 months of life and, if so, age when the foal left the farm; whether the foal was exposed to another breeding farm during the first 6 months of life and, if so, whether the foal was exposed to another farm that had a history of *R equi* infection; whether the foal was directly exposed to another foal that had *R equi* pneumonia (ie, another foal in the same pasture or paddock or in an adjacent stall at the same time); whether the foal was indirectly exposed to another foal that had *R equi* pneumonia (ie, used the same stall, paddock, or pasture but not at the same time); age of the foal when it was first turned out to paddock or pasture (ie, < 1 week, 1 to 2 weeks, 3 to 4 weeks, 5 to 8 weeks, or > 8 weeks); age at which the foal was no longer stalled (ie, < 4 weeks, 4 to 8 weeks, 9 to 20 weeks, > 20 weeks, always stalled, or never stalled); whether the foal commingled with other mare-foal pairs (ie, mare and foal were housed in a paddock separate from other mare-foal pairs; housed with 2 to 5 mare-foal pairs, 6 to 10 mare-foal pairs, or > 10 mare-foal pairs; or other); housing of the foal during the first week of life (ie, stall only, pasture or paddock only, combination of stall and pasture or paddock, or other); housing of the foal from 1 to 4 weeks of age (ie, stall only, pasture or paddock only, combination of stall and pasture or paddock, or other); housing of the foal from 5 to 8 weeks of age (ie, stall only, pasture or paddock only, combination of stall and pasture or paddock, or other); housing of the foal from 9 to 24 weeks of age (ie, stall only, pasture or paddock only, combination of stall and pasture or paddock, or other); and age of foal when weaned from dam.

All foals were evaluated for any signs of illness during the first 6 months of life. Information collected included whether the foal had any infectious respiratory tract disorder other than *R equi* pneumonia during the first 6 months of life and whether the foal developed *R equi* pneumonia during the first 6 months of life and, if so, whether the foal died, was euthanatized, or recovered.

Data analysis—Categories for some covariates (eg, number of mare-foal pairs that were commingled) were consolidated on the basis of results of bivariate analyses. Consolidation was performed in such a way that the consolidated categories best characterized the observed association. For example, consolidation of the categories for duration of residence of the dam at the farm into a dichotomous variable enabled us to examine the association between a foal developing *R equi* pneumonia and residence of the dam on the farm for ≥ 1 year versus < 1 year. Some continuous covariates were categorized for analysis. Categories were determined on the basis of exploratory data analyses, with the median or 25th and 75th percentiles used as category cut-points.

The relationship between the dichotomous outcome of disease (*R equi* pneumonia vs no *R equi* pneumonia) and independent categoric variables (eg, farm) was examined by means of 2-way and multiway contingency comparisons; the χ^2 and Fisher exact tests were used to compare proportions.[22] The relationship between *R equi* pneumonia and independent continuous variables (eg, duration of gestation) was examined by use of Wilcoxon rank-sum tests.[22] **Odds ratios (ORs)** were calculated as a crude measure of the association between single putative risk factors and *R equi* pneumonia. Odds ratios were obtained by means of logistic regression.[23]

Because farm was significantly associated with outcome (ie, *R equi* pneumonia vs no *R equi* pneumonia), all covariates that were associated with *R equi* pneumonia at a value of $P \leq 0.15$ were examined in a multiple logistic regression model that included the effect of farm along with the covariate of interest (eg, year of birth). Results of bivariate and trivariate (ie, outcome, farm, and covariate of interest) analyses were recorded. After adjustment for the effects of farm, all variables that were associated with *R equi* pneumonia at a value of $P \leq 0.15$ were examined in multiple logistic regression analysis. Variables for which data were missing for ≥ 25% of the study population were excluded from multivariate modeling.

Stepwise multiple logistic regression equations[23] were constructed to obtain estimates of the magnitude and direction of the association of *R equi* pneumonia with multiple factors and obtain estimates of ORs for single variables adjusted for the effects of other variables associated with *R equi* pneumonia. Variables were selected for inclusion in multivariate models by means of a combination of backward and forward stepwise procedures. A likelihood ratio χ^2 test was used, with a value of $P < 0.12$ needed for a variable to be entered in the model and a value of $P > 0.15$ used as the cutoff for removal. All possible bivariate interactions among main effects variables that were significantly associated with *R equi* pneumonia were examined. Logistic regression analyses were conducted with a commercially available statistical program.[d] Confidence limits for the ORs were derived by use of maximum-likelihood estimators.[23] Goodness-of-fit was assessed by use of the method of Hosmer and Lemeshow.[23] For all analyses, a value of $P \leq 0.05$ was considered significant.

Results

General information—Two farms met the requirements for participation in the study, and both agreed to participate for a 2-year period. Farm 1 was a large Quarter Horse breeding farm; farm 2 was a large Arabian breeding farm. Both farms were located in central Texas and were approximately 75 miles apart. Both farms had a resident veterinarian who was present on the farm on a daily basis. During the previous 5 years, both farms had *R equi* pneumonia morbidity rates of 20% to 40%.

Information was collected for 220 foals over the 2-year period, of which 32 (15%) met the study criteria for having developed *R equi* pneumonia. Of the 32 foals that developed *R equi* pneumonia, 4 (12.5%) died. Foals at farm 2 were significantly ($P < 0.001$) more likely to develop *R equi* pneumonia (32.5%; 25/77) than were foals at farm 1 (4.9%; 7/143). Because of this difference in prevalence of disease between the 2 farms, bivariate analyses of the association between independent covariates and disease were performed, along with trivariate analyses adjusting for the effects of farm because farm confounded the association with disease for many covariates.

All foals from farm 2 were Arabians, and all foals from farm 1 were Quarter Horses (n = 141) or Thoroughbreds (2). Consequently, it was not possible to distinguish breed effects from farm effects. Sex of the foal was not associated with development of *R equi* pneumonia.

The risk of *R equi* pneumonia was greater during 2000 than 1999 (**Table 1**). This difference remained significant even after adjusting for farm effect. At farm 1, the prevalence of *R equi* pneumonia was 3.8% (3/79 horses) during 1999 and 6.3% (4/64) during 2000; at farm 2, the prevalence of *R equi* pneumonia was 21.6% (8/37) during 1999 and 42.5% (17/40) during 2000.

The proportion of unaffected foals born between January and March was significantly ($P = 0.004$) greater than the proportion of affected foals born during this period. However, this difference was not significant after adjusting for the effect of farm (Table 1).

Dam-related factors—There was no significant difference in age distribution between dams of unaffected foals and dams of affected foals. Duration of gestation for unaffected foals was significantly ($P < 0.001$) greater than that for affected foals; however, this difference was not significant after adjusting for the effect of farm (Table 1). Even when duration of gestation was considered as a categoric variable (≤ 325 days of gestation vs > 325 days of gestation), there was no significant difference in duration of gestation between affected and unaffected foals after adjusting for the effect of farm.

The proportion of unaffected foals for which the dam had been housed at the farm for > 1 year was significantly ($P = 0.002$) less than the proportion of affected foals for which the dam had been housed at the farm for > 1 year; however, this difference was not significant after adjusting for the effect of farm (Table 1). Illness of the dam during the last 3 months of gestation or first 3 months of lactation was not significantly associated with development of *R equi* pneumonia in foals.

There was no significant difference in parity between dams of affected and unaffected foals. When parity was considered as a dichotomous variable (parity ≤ 4 vs parity > 4), foals from dams with parity > 4 had a significantly increased risk of *R equi* pneumonia. However, this difference was not significant after adjusting for the effect of farm (Table 1).

There were no significant differences between dams of affected and unaffected foals with respect to whether the dam had a history of a previous foal affected by *R equi* pneumonia, the number or proportion of the dam's previous foals that developed *R equi* pneumonia, or the proportion of the dams that had had an affected foal the previous year.

Factors related to foal birth—All 77 foals at farm 2 were born on the farm, whereas 136 foals at farm 1 were born on the farm and 7 foals were born elsewhere. At farm 1, *R equi* pneumonia was significantly ($P = 0.038$) more common among foals born elsewhere (2/7) than among foals born on the farm (3.7%; 5/136).

Most foals (95%; 209/220) were born in designated foaling stalls; location of birth was not significantly associated with *R equi* pneumonia. Although the proportion of affected foals born in stalls with concrete floors was significantly ($P < 0.001$) greater than the proportion of unaffected foals born in such stall, this difference was attributable to the fact that all foals born in stalls with concrete floors were from farm 2. Although foals with *R equi* pneumonia were significantly ($P < 0.001$) more likely to have been born in stalls bedded with straw than were unaffected foals, this finding was not significant after adjusting for the effect of farm. There was no difference between affect-

Table 1—Results of bivariate and trivariate conditional logistic regression analysis of various potential foal-related risk factors for *Rhodococcus equi* pneumonia among 220 foals on 2 equine breeding farms in Texas on which *R equi* infection was endemic

Variable	No. of affected foals (%)	No. of unaffected foals (%)	Bivariate analysis			Trivariate analysis*		
			Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Foal at farm 2	25/32 (78.1)	77/188 (41.0)	9.34	3.81–22.91	< 0.001	NA	NA	NA
Foal born in 2000	21/32 (65.6)	83/188 (44.1)	2.42	1.10–5.29	0.028	2.34	1.01–5.43	0.047
Foal born between January and March	14/32 (43.8)	131/188 (69.7)	0.34	0.16–0.73	0.006	0.69	0.30–1.63	0.401
Gestation > 325 days	16/30 (53.3)	126/169 (74.6)	2.56	1.16–5.69	0.020	1.01	0.41–2.47	0.988
Dam at farm > 1 year	23/30 (76.7)	83/183 (45.4)	3.96	1.62–9.68	0.003	0.94	0.30–2.96	0.912
Dam's parity > 4	12/26 (46.2)	20/86 (23.4)	5.04	2.15–11.82	< 0.001	1.79	0.69–4.62	0.230
Antimicrobials during first week of life	1/32 (3.1)	28/185 (15.1)	0.18	0.01–0.90	0.099	0.19	0.02–1.55	0.122
Supplemental immunoglobulins other than *Escherichia coli* antiserum	2/32 (6.2)	37/184 (20.1)	0.26	0.06–1.16	0.078	0.85	0.16–4.37	0.850
Exposed to paddock or pasture at < 2 weeks of age	29/32 (90.6)	112/172 (65.1)	5.18	1.52–17.70	0.009	1.80	0.45–7.26	0.407
No longer stalled at < 1 month of age	18/32 (56.2)	29/179 (16.2)	6.65	2.98–14.85	< 0.001	3.01	1.22–7.45	0.017
Housed in groups of 2 to 5 mare-foal pairs	8/32 (25.0)	105/176 (59.7)	0.22	0.10–0.53	< 0.001	0.31	0.12–0.75	0.010
Housed in groups of ≤ 5 mare-foal pairs	11/32 (34.4)	137/177 (77.4)	0.15	0.07–0.34	< 0.001	0.32	0.13–0.81	0.016
Stalled exclusively at 1 to 4 weeks of age	5/32 (15.6)	77/185 (41.6)	0.26	0.10–0.70	0.008	1.19	0.30–4.69	0.807
History of other infectious respiratory tract diseases	5/32 (15.6)	34/185 (18.4)	0.82	0.30–2.29	0.708	0.32	0.11–0.96	0.043

*Adjusted for effect of farm.
CI = Confidence interval. NA = Not applicable.

ed and unaffected foals with regard to whether birth was attended by farm personnel. Similarly, whether antimicrobials were administered during the first week of life was not significantly associated with whether foals developed *R equi* pneumonia (Table 1).

Factors related to passive immunity status—There were no significant differences between affected and unaffected foals in regard to specific gravity of presuckle colostrum, whether the foal stood and suckled within 3 hours after birth, or whether the foals received colostrum from the dam (via ingestion or nasogastric intubation). There was also no difference between unaffected and affected foals in regard to age at which foals were tested for adequacy of passive transfer of immunoglobulins. Multiple assays were used on the farms to measure foal serum IgG concentrations, including a radial immunodiffusion assay[e] (1 foal), glutaraldehyde coagulation assay[f] (135 foals), latex agglutination assay[g] (65 foals), and membrane filter ELISA kit[h] (12 foals). There was no difference between affected and unaffected foals in regard to the proportion of foals with serum IgG concentrations < 800 mg/dL. There were no significant differences between affected and unaffected foals in regard to whether they received non-*R equi* plasma, concentrated equine serum IgG, bovine colostrum, *S* Typhimurium antiserum, frozen colostrum via nasogastric intubation, or colostrum from the dam via bottle-feeding.

Affected foals were significantly ($P < 0.001$) less likely than unaffected foals to have received some form of supplemental immunoglobulins; however, this was not significant after adjusting for the effect of farm. At farm 1, 132 of 138 foals received *E coli* antiserum. The proportion of affected foals at farm 1 that received antiserum (71.4%; 5/7) was significantly ($P = 0.03$) less than the proportion of unaffected foals that did (97%; 127/131). Although the proportion of affected foals that received supplemental immunoglobulins other than *E coli* antiserum was less than the proportion of unaffected foals that did, this difference was not significant (Table 1).

Twenty-nine foals received REHP IV. All foals that received REHP were from farm 1, and the plasma was from a single commercial source.[i] Although the proportion of affected foals (6.25%; 2/32) that received REHP was less than the proportion of unaffected foals (14.9%; 27/181) that did, the difference was not significant. When restricted to foals at farm 1, there still was no significant difference between affected (2/7; 28.6%) and unaffected (27/129; 20.9%) foals.

Factors related to foal management—All foals at farm 2 were born on the farm. Seven foals at farm 1 were not born on the farm. For these 7 foals, median age at the time of arrival at the farm was 4 days (range, 3 to 58 days). Two of these 7 foals developed *R equi* pneumonia; they were 3 and 58 days old when they arrived at the farm.

There was no difference in the proportions of

unaffected and affected foals that were shipped off the farm during the first 6 months of life. Of the 220 foals, 109 were reported to have left the farm before 6 months of age. Age at the time of leaving the farm for 105 unaffected foals was lower ($P = 0.051$) than age for 4 affected foals; however, this difference was not significant after adjusting for the effect of farm. There were no differences between proportions of unaffected and affected foals that had been exposed during the first 6 months of life to another breeding farm or another breeding farm with a history of *R equi* pneumonia. There were no significant differences between affected and unaffected foals regarding whether they were directly or indirectly exposed to another foal with *R equi* infection during the first 6 months of life.

Unaffected foals (81.1%; 150/185) were not significantly ($P = 0.112$) more likely than affected foals (68.8%; 22/32) to be housed exclusively in a stall during the first week of life. Unaffected foals were significantly ($P = 0.008$) more likely than affected foals to be housed exclusively in a stall from 1 to 4 weeks of age; however, this was not significant after adjusting for the effect of farm (Table 1). There was no apparent association between disease status and housing location of foals at 4 to 8 or 8 to 24 weeks of age.

The age at which foals were first exposed to a paddock or pasture was considered as a dichotomous variable (turned out in a paddock or pasture at < 2 weeks of age or not). Affected foals were significantly ($P = 0.009$) more likely than unaffected foals to be turned out in a paddock or pasture at < 2 weeks of age; however, this difference was not significant after adjusting for the effect of farm (Table 1). Affected foals were significantly ($P < 0.001$) more likely than unaffected foals to have been no longer stalled at < 1 month of age, and this variable was still significant ($P = 0.017$) after adjusting for the effect of farm.

The size of commingled groups of mare-foal pairs in pastures or paddocks was reported for 209 foals. The proportion of mare-foal pairs housed in separate paddocks was greater among unaffected (18.6%; 33/177) than affected (9.4%; 3/32) foals; however, this difference was not significant, and farm did not influence this association. Affected foals were significantly ($P < 0.001$) less likely to have been housed in groups of 2 to 5 mare-foal pairs than were unaffected foals, and this association remained significant after adjusting for the effect of farm (Table 1). Proportions of affected foals turned out in groups of 2 to 5 mare-foal pairs at farms 1 and 2 (28.6% [2/7] and 24% [6/25], respectively) were lower than proportions of unaffected foals (64.8% [81/125] and 47.1% [24/51], respectively). Affected foals (56.3%; 18/32) were significantly ($P < 0.001$) more likely to have been housed in groups of 6 to 10 mare-foal pairs than were unaffected foals (15.3%; 27/176). However, there were no foals housed in groups of 6 to 10 mare-foal pairs at farm 1, and although the proportion of affected foals housed in groups of 6 to 10 mare-foal pairs at farm 2 (72%; 18/25) was greater than the proportion of unaffected foals (52.9%; 27/51), the difference was not significant.

When the size of commingled groups of mare-foal pairs was examined as ≤ 5 mare-foal pairs versus > 5 mare-foal pairs, unaffected foals were significantly ($P < 0.001$) more likely to have been housed in paddocks or pastures in groups of ≤ 5 mare-foal pairs than were affected foals; this association remained significant even after adjusting for the effect of farm (Table 1). At farm 1, 57.1% (4/7) of affected foals versus 89.7% (113/126) of unaffected foals were commingled in groups of ≤ 5 mare-foal pairs. At farm 2, 28% (7/25) of affected foals versus 47.1% (24/51) of unaffected foals were commingled in groups of ≤ 5 mare-foal pairs.

Weaning age differed significantly between affected and unaffected foals, but this difference appeared to be attributable to the effect of farm. Age at the time of weaning was also considered as a dichotomous variable (weaned at 3 to 5 months of age vs not). Although the proportion of affected foals weaned at 3 to 5 months was significantly ($P < 0.001$) greater than the proportion of unaffected foals, this difference appeared to be attributable to differences in weaning practices between farms.

Factors related to other respiratory tract disease—Information on whether foals had any infectious respiratory tract disorder other than *R equi* pneumonia was available for 217 foals. Proportion of affected (15.6%; 5/32) and unaffected (18.4%; 34/185) foals that had such a history was similar. After adjusting for the effect of farm, however, affected foals were significantly less likely to have had such history (Table 1).

Multiple logistic regression and multivariate analysis—After accounting for the effects of year and farm, administration of antimicrobials during the first week of life was not significantly associated with development of *R equi* pneumonia. Similarly, after accounting for the effects of year and farm, neither age at which foals were no longer stalled nor exposure to pasture or paddock at < 2 weeks of age ($P = 0.115$) was significantly associated with the risk of *R equi* pneumonia (**Table 2**). Finally, after accounting for the effects of year and farm, whether foals were commingled at pasture in small groups (≤ 5 mare-foal pairs) was not significantly ($P = 0.07$) associated with risk of disease.

Table 2—Multiple logistic regression models of potential foal-related risk factors for *R equi* pneumonia among 220 foals on 2 equine breeding farms in Texas on which *R equi* infection was endemic

Variable	Odds ratio	95% CI	*P* value
Model 1			
Farm 2	5.36	1.91–15.02	0.001
Year 2000	1.49	0.59–3.79	0.401
Foals commingled with ≤ 5 mare-foal pairs	0.39	0.14–1.09	0.071
Model 2			
Farm 2	5.17	1.76–15.23	0.003
Year 2000	2.70	1.13–6.44	0.025
Foals turned out at < 2 weeks of age	3.28	0.75–14.44	0.115

Discussion

In the present study, we used the most accurate diagnostic criteria possible within the confines of a farm-based study to categorize individual foals as affected or unaffected with *R equi* pneumonia. Two practitioners participated in this study; therefore, it was essential to choose diagnostic criteria for *R equi* pneumonia that were suitable for the equipment available and to the diagnostic preferences and experience of these practitioners. Variability in diagnostic methods resulted from variations in practitioner experience, availability of radiographic and sonographic equipment, availability of clinicopathologic and microbiologic services, individual preferences of the horse owners, economic considerations, and other considerations. A recognized limitation of our criteria for an affected foal was the possibility of misdiagnosis. Clinically normal foals in this study did not undergo repeated thoracic radiography, thoracic ultrasonography, or transtracheal aspiration to definitively characterize them as unaffected. Such standardized testing of all foals was considered during study design but was not considered practical by the participating farms. Foals < 3 weeks or > 24 weeks old that developed pneumonia were not considered as affected foals because *R equi* pneumonia is uncommon in foals in those age groups.[2-4]

Equine breeding farms in Texas were solicited to participate in this study. Farms with endemic *R equi* infection were identified through previous studies[6,7] in which Texas veterinarians provided farm-related management data from farms with foals with *R equi* pneumonia. Thirty-two farms were screened, and only 2 breeding farms met the criteria for inclusion in this study. Thus, an important limitation of the present study was the small sample size. We obtained data for 32 affected foals and 188 unaffected foals from 2 farms during the 2-year study period. Although this number of foals exceeds the numbers in other reports in the literature, it is still a relatively small number of foals. Because of the small sample size, some ORs were somewhat unstable (ie, had wide 95% confidence limits). Consideration must be given to this when interpreting these data, particularly the results of multivariate analyses. Studies of larger populations of foals from farms where the infection is endemic are needed to overcome this sample size limitation.

Another limitation of the present study is that it was performed at only 2 farms in Texas. Thus, results may be difficult to extrapolate to other farms within or outside Texas. Despite the limitations mentioned, we believe the results of this study provide useful information for veterinarians and horse owners in regard to foal-related risk factors associated with *R equi* foal pneumonia.

One of the criteria for selection of participating farms in the present study was a historical morbidity rate of *R equi* pneumonia > 20%. Farm 1 had only a 4.9% morbidity rate during the 2 years of the study, compared with morbidity rates of 20% to 40% in previous years. The reasons for this sudden decline in morbidity rate during the 2 years of this study were unknown; however, we suspect it may have been related to changes in the horse population during those years. During 1999, the first year of the study, the population of horses and foals at this predominately Quarter Horse breeding farm changed considerably, owing to the American Quarter Horse Association permitting registration of horses bred by artificial insemination with fresh cooled semen. The number of transient mares and foals at farm 1 declined markedly during that year, presumably because more mares were bred by artificial insemination rather than actually being transported to the farm. The resultant smaller population of mares and foals on the same acreage resulted in a lower foal density on the premises, and we have previously demonstrated that farms with a large population of mares, a population of transient mares, and a high foal density had an increased risk of foals developing *R equi* pneumonia.[6] Such factors may have played an important role at farm 1 in reducing the prevalence of *R equi* pneumonia during 1999 and 2000.

Data in the present study showed a significant effect of farm on the risk of *R equi* pneumonia. Foals at farm 2 were significantly more likely to develop *R equi* pneumonia (32.5%) than were foals at farm 1 (4.9%). Because of this difference in prevalence of disease between the 2 farms, it was necessary to consider all bivariate associations of independent covariates with disease alone and after adjusting for the effect of farm because farm confounded the association with disease for many covariates. There are clear farm-related risk factors for *R equi* foal pneumonia, including large acreage, large populations of mares and foals, and a transient population of mares and foals.[6,7] Other reports[12,14,24] have revealed that virulent *R equi* containing an 85- to 90-kilobase plasmid are distributed at a higher concentration in horses and their environment on breeding farms with a history of *R equi* infection than on those without such history. Another study,[25] however, reported a lack of association between *R equi* disease status of a farm and isolation of virulent or avirulent *R equi* from soil on that farm. One report[9] suggested that farms that have housed horses for many years have progressive accumulation of *R equi* in the environment and thus have a higher prevalence of disease. However, we recently demonstrated that the number of years a farm was used for housing horses was not associated with the risk of foals developing *R equi* pneumonia in Texas.[6] A recent report failed to detect geochemical factors of soils from affected and unaffected farms.[26] There are clearly strong farm-related effects on the risk of *R equi* foal pneumonia; thus, it is not surprising that the 2 farms in this study had markedly different prevalence rates of *R equi* infection.

Our data also showed a significant effect of year on the risk of *R equi* pneumonia. The risk of *R equi* pneumonia was greater during 2000 than 1999, and this difference remained significant after adjusting for the effect of farm. The overall prevalence of *R equi* pneumonia for the 2 study farms was 9.5% during 1999 and 20.2% during 2000. We did not collect data regarding weather conditions on the farms during these 2 years, but multiple factors may have played a role in this difference in prevalence. Reasons for differences in prevalence of *R equi* pneumonia from year to year are large-

ly unproven but may include environmental factors such as the concentration of virulent *R equi* in the air and soil, amount of rainfall, and dusty condition of pastures and paddocks.[24] *Rhodococcus equi* does not thrive under wet soil conditions but can readily be isolated from dry soil.[27,28] One report[29] describes the highest incidence of disease coinciding with the driest climatic and pasture conditions. Takai et al[12] demonstrated that *R equi* was more concentrated in the airborne environment during dry, windy conditions than during damp, calm weather conditions. Characteristics of the horse population on the farm during a given year may also affect the prevalence of *R equi* foal pneumonia.[6] Also, management factors at the farm (ie, administration of hyperimmune plasma) may play an important role in determining the prevalence of *R equi* foal pneumonia during a given year.[7]

One hundred thirty-two of the newborn foals at farm 1 received a dose of *E coli* antiserum orally. Unaffected foals (97%) were more likely to have received the antiserum than were affected foals (71.4%). However, although this finding was significant on the lower prevalence study farm, we are reluctant to conclude that this product reduces the risk of *R equi* pneumonia because of the small number of affected foals on farm 1. In a previously reported randomized, prospective, clinical trial,[30] administration of *E coli* antiserum to newborn foals did not significantly affect the frequency or cause of infectious disease or death. The effect of *E coli* antiserum on the proportion of foals affected with *R equi* pneumonia was not reported for that study; however, there was no significant difference between the proportions of treated and untreated foals that developed *R equi* pneumonia (MKC, NDC).

The small number of foals that received REHP in this study made it difficult to assess the effectiveness of REHP for the prophylaxis of *R equi* pneumonia. Twenty-nine foals from farm 1 received commercially available REHP. The proportion of affected foals (6.25%) that received REHP was less than the proportion of unaffected foals (14.9%) that did; however, this did not represent a significant difference. On the other hand, the small number of foals receiving REHP resulted in markedly limited statistical power. The immunoprophylactic effect of REHP has been demonstrated in experimentally infected foals[31] and in farm-based studies.[32,33] Another report[34] suggested that REHP was not effective at decreasing the prevalence of *R equi* pneumonia. A recently published clinical trial[35] showed no significant difference in the incidence of *R equi* pneumonia between foals that received REHP (19.1%) and control foals (30%). The mechanism by which REHP protects against disease remains unknown.[4,31-36] Also unknown are the optimum dosage of REHP that should be administered and the ideal age at which REHP should be administered.[3,4,34-36]

In the present study, we evaluated several variables to try to determine whether housing practices affected a foal's risk of developing *R equi* pneumonia. Affected foals were significantly more likely than unaffected foals to have been no longer stalled at < 1 month age, and this association remained significant after adjusting for the effect of farm, although it was not retained in the multivariate analysis. This may suggest that maintaining foals in a stalled environment during the early weeks of life might have a protective effect. A recent report[37] suggests that foals become infected with *R equi* early in life. Thus, exposure to a pasture or paddock environment that is contaminated with virulent *R equi* during this age period may increase the risk of infection. *Rhodococcus equi* multiplies in the intestine of foals during the first 8 weeks of life, and multiplication ceases by 12 weeks of age.[18] Fecal contamination of pastures and paddocks with virulent *R equi* likely serves as a mechanism of exposure for foals; therefore, minimizing foal contact with the contaminated pasture and paddock environments could lower the risk of developing *R equi* pneumonia. There are likely differences in risk associated with various types of outdoor environments; however, our study did not differentiate whether foals were turned out into pastures or paddocks. Data were simply collected regarding foal exposure to outdoor environments. In addition, we did not collect information regarding whether foals were exposed to well-grassed or poorly grassed outdoor environments. Future studies should more thoroughly characterize the risks associated with size and grass quality of the outdoor environments.

We also found that affected foals in the present study were more likely to have been housed in paddocks or pastures in large groups (> 5 mare-foal pairs) than were unaffected foals, and this association remained significant after adjusting for the effect of farm, although it was not significant in multivariate analyses. This finding may suggest that commingling of mare-foal pairs in smaller groups (≤ 5 mare-foal pairs) has a protective effect on the risk of developing *R equi* pneumonia. We suspect that this finding represents higher foal density in a turn-out environment associated with larger groups of commingled mare-foal pairs; however, we did not specifically collect data on the density of foals in the turn-out environment. A previous report[6] of farm-related risk factors demonstrated that high foal density may result in increased risk of foals developing *R equi* pneumonia. Another potential explanation for this finding is that housing foals in larger mare-foal groups may expose individual foals to an environment with larger amounts of fecal material from other mares and foals. *Rhodococcus equi* grows better in soils that are enriched with feces than in soil alone, presumably because of the presence of acetate and propionate in horse feces.[28] Such an environment would likely result in greater exposure of individual foals to virulent *R equi*.[14,28]

In trivariate analyses in the present study, we found that affected foals were significantly less likely than unaffected foals to have had other infectious respiratory tract diseases. We doubt that this finding is biologically important. One possible explanation for this finding is that foals with *R equi* pneumonia may indeed have had other infectious respiratory tract diseases concurrently or independently of *R equi* pneumonia, but that the veterinarians did not recognize the other infectious respiratory tract diseases and instead attributed the clinical signs strictly to *R equi* pneumonia. Another possibility is that foals with *R equi* pneumonia were

receiving antimicrobial treatment for *R equi* pneumonia and thus were protected against some other common bacterial respiratory tract pathogens of foals, such as *Streptococcus equi* and *S zooepidemicus*.

The case fatality rate for the 32 affected foals in the present study was 12.5%, which was considerably lower than rates in other reports. A previous study[6] of 32 equine breeding farms with foals with *R equi* pneumonia reported an overall case fatality rate of 29.2%, with a median farm case fatality rate of 25%. On a Thoroughbred breeding farm in New South Wales, a mortality rate of 42% (8/19 foals) was reported.[38] Retrospective studies[5,39-45] cite mortality rates ranging from 12% to 80%. The reasons for the relatively low case fatality rate of foals in the present study are unknown, but heightened awareness of the disease on behalf of farm personnel and veterinarians, as well as increased use of diagnostic methods for early detection of affected foals and appropriate treatment, likely played a role.

In summary, the present study did not identify any apparent foal-related risk factors for *R equi* pneumonia on farms where the disease is endemic, although there were clear farm- and year-related effects on the risk of *R equi* pneumonia. Studies of farm-related risk factors[6,7] may be more revealing than studies of foal-related risk factors; however, studies of foal-related risk factors performed on larger populations of foals and farms are needed to substantiate this conclusion. In addition, studies that examine the immune function of affected and unaffected foals before and after the onset of clinical signs of pneumonia are needed to better understand why some foals on farms on which *R equi* pneumonia is endemic develop the disease while other foals do not.

[a]Seramune, Sera Inc, Shawnee Mission, Kan.
[b]Endoserum, *Salmonella typhimurium* antibody (equine origin), IMMVAC Inc, Columbia, Mo.
[c]Equine Coli Endotox, *Escherichia coli* antiserum, Grand Laboratories Inc, Larchwood, Iowa.
[d]SAS/STAT, SAS Institute Inc, Cary, NC.
[e]RID, VMRD Inc, Pullman, Wash.
[f]Gamma Check-E, Veterinary Dynamics Inc, Templeton, Calif.
[g]Foalcheck, Haver Lockhart, Shawnee, Kan.
[h]CITE Foal IgG test kit, Idexx Laboratories Inc, Westbrook, Me.
[i]Polymune R, Veterinary Dynamics Inc, Templeton, Calif.

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