Evaluation of equine breeding farm characteristics as risk factors for development of *Rhodococcus equi* pneumonia in foals

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Objective—To identify farm characteristics as risk factors for the 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, 1 for a farm with ≥ 1 foal with *R equi* pneumonia and 1 for an unaffected control farm. Matched data were compared by use of conditional logistic regression analysis.

Results—Farm characteristics found in bivariate analyses to be associated with increased risk for pneumonia caused by *R equi* in foals included > 200 farm acres, ≥ 60 acres used in the husbandry of horses, > 160 horses, ≥ 10 mares housed permanently on the farm (resident mares), > 17 foals, > 0.25 foals/acre, and the presence of transient mares (mares brought temporarily to the farm for breeding or foaling) and their foals. Affected farms were significantly more likely to be > 200 acres in size and have ≥ 10 resident dam-foal pairs, whereas control farms were significantly more likely to have ≥ 75% of their dam-foal pairs housed permanently on the farm.

Conclusions and Clinical Relevance—Breeding farms with large acreage, a large number of mares and foals, high foal density, and a population of transient mares and foals are at high risk for foals developing pneumonia caused by *R equi*. (*J Am Vet Med Assoc* 2003;222:467–475)

Pneumonia is a major cause of illness and death for foals worldwide. Data regarding the incidence, prevalence, and economic impact of equine infectious diseases are limited, but results of 1 large-scale study[1] indicated that respiratory disease is the most common cause of foal illness and death in Texas. Although many microorganisms may cause pneumonia in foals, the bacterium *Rhodococcus equi* is considered the most common cause of severe pneumonia[2-5]; the disease is insidious and most frequently affects foals 1 to 4 months of age.[2,3] In addition to pyogranulomatous pneumonia, *R equi* has been identified as the causative agent of numerous extrapulmonary disorders of foals, including enterocolitis, lymphadenitis, nonseptic polysynovitis, and osteomyelitis.[6,7] *Rhodococcus equi,* previously called *Corynebacterium equi*, is a gram-positive soil-saprophytic facultative intracellular pathogen that has worldwide distribution.[2,3] The pathogenesis of *R equi* infection in foals is not fully understood,[2,3,8-15] although the main routes of infection are thought to be via the respiratory and alimentary tracts.[3,8,12-14]

Rhodococcus equi infection has a substantial impact on equine breeding farms for numerous reasons. Prevalence and case fatality rates are high.[3-5,16] Definitive diagnosis is challenging, particularly in the early stages of infection.[4,5] Treatment is generally prolonged, expensive, associated with adverse effects, and not always successful.[3,16,17-22] Pneumonia caused by *R equi* negatively affects future athletic performance.[16] Breeding farms on which *R equi* pneumonia is reputedly endemic may suffer a loss of clients.[5] The only immunoprophylactic strategy available involves administration of hyperimmune plasma; this is expensive and labor-intensive and may be impractical or ineffective.[23-26]

Notable advancements in the understanding of *R equi* pneumonia in foals have been realized during the past decade. Despite these advancements, however, control and prevention of *R equi* pneumonia have not been achieved. Knowledge of risk factors associated with transmission of the microorganism and development of the disease is limited. Although epidemiologic studies of *R equi* pneumonia have been reported,[27-44] few have investigated farm characteristics and management practices that may predispose foals to development of pneumonia caused by *R equi*.

Rhodococcus equi infection in horses is endemic on some farms yet may be encountered sporadically or not at all on others.[3,10,30,36] Results of immunologic testing of most horses, however, indicate exposure to the bacterium is widespread.[2,40] The organism usually inhabits soil and has simple growth requirements that are met adequately by the combination of herbivore manure and summer temperatures.[3,10] In a report[27] from Ontario, Canada, a correlation between the number of *R equi* organisms in farm soils and the number of cases of *R equi* pneumonia was identified. Results of studies[2,33-38,45] from Japan, however, indicate that prevalence of infection on a farm depends on the magnitude of contamination with virulent *R equi* (containing 15- to 17-kDa anti-

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gens and their associated 85- to 90-kb plasmids) of horses and their environment. Environmental factors, farm characteristics, farm management procedures, and preventative health practices may also be associated with development of *R equi* pneumonia in foals. Identification of specific risk factors is important, as recommendations may then be made to decrease the prevalence and economic impact of *R equi* pneumonia in foals on severely affected farms.

The purpose of the study reported here was to identify specific farm characteristics that are risk factors for development of *R equi* pneumonia in foals on breeding farms.

Materials and Methods

Participating veterinarians—This study was performed in conjunction with a study[46] to identify farm management and preventative health practices associated with *R equi* pneumonia in foals on equine breeding farms. Participating veterinarians were residents of Texas and during 1997 were members of the American Association of Equine Practitioners or the Texas Veterinary Medical Association working in equine, large animal, or mixed-animal practices, which included care of large animals. Veterinarians who were retired, employed by a university, or not actively engaged in equine practice in Texas were excluded. Participation was solicited from 774 veterinarians by mail; compensation ($150) was offered to veterinarians for data they collected from a matched pair of farms. Of the 774 veterinarians, 82 (10.6%) indicated willingness to participate in the study, 55 (7.1%) declined to participate, and the remaining 637 (82.2%) did not respond to the letter of solicitation.

Data collection—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. A foal was considered to have *R equi* pneumonia if clinical signs of pneumonia were present and *R equi* was isolated from a tracheobronchial aspirate or postmortem lung specimen, or if the foal showed clinical signs of pneumonia and at least 2 of the following were identified: multifocal pulmonary opacities visible on thoracic radiographs, ultrasonographic evidence of pulmonary abscesses, gram-positive intracellular coccobacilli observed during cytologic evaluation of transtracheal wash specimens, or a 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 its foal were defined as a dam-foal pair.

Data collection forms (for an affected farm and for a control farm) and stamped return envelopes were mailed to participating veterinarians in January 1997. Veterinarians were requested to identify 1 affected and 1 control farm in Texas during 1997 and return completed data collection forms for a pair of farms by March 1, 1998.

General information about study farms—General information collected for all farms included date of completion of the data form, name of veterinarian, name of farm or farm owner, classification of farm (affected or control), location of farm within Texas (county), number of years farm had been used for raising horses > 24 weeks of age, and number of years farm had been used for raising foals < 24 weeks of age.

Information related to *R equi* pneumonia in foals—Pertinent disease data from all farms included number and percentage of foals that developed *R equi* pneumonia, number of foals with *R equi* pneumonia that died or were euthanatized, number of foals with *R equi* pneumonia that recovered completely, number of foal deaths unrelated to development of *R equi* pneumonia, total number of foal deaths, and percentage of foals (0, 1 to 25, 26 to 50, 51 to 75, 76 to 100) that developed *R equi* pneumonia during the 3 previous years (1994, 1995, and 1996). Morbidity rate was determined by dividing the number of affected foals by the total number of foals on the farm. Case fatality rate was determined by dividing the number of foals that died as a result of developing *R equi* pneumonia by the number of affected foals.

Breeds of horse, farm acreage, and horse population—Data regarding breeds of horse, farm acreage, and horse population collected for each farm included predominant breed of horse on the farm (Thoroughbred, Quarter Horse type [Quarter Horse or Paint], Arabian, or other), acreage of the farm, acreage used in the husbandry of horses, number of horses (including foals) on the farm, number of foals on the farm, numbers of resident and transient mares, numbers of resident and transient maiden mares, numbers of resident and transient barren mares, numbers of resident and transient dam-foal pairs, 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), numbers of resident and transient mares in various age groups (< 5 years, 5 to 10 years, 11 to 15 years, 16 to 20 years, or > 20 years), number of transient mares that delivered foals on the farm, and number of transient mares that delivered foals at another facility.

The density of horses was determined by dividing the total number of horses on the farm by the total number of acres used in the husbandry of horses. The density of foals was determined by dividing the total number of foals on the farm by the total number of acres used in the husbandry of horses.

Categories for certain covariates were consolidated on the basis of results of bivariate analysis (eg, percentage of dam-foal pairs that were transient). Consolidation was performed when an apparent classification best characterized the observed association. For example, consolidation of the 4 categories representing farms with transient dam-foal pairs into 1 category facilitated assessment of the association between development of the disease and the presence of transient dam-foal pairs on the farm. In relation to the absence of transient dam-foal pairs, the other 4 categories added no new information about the magnitude or direction of the estimated association; consequently, the variable levels were collapsed into a single dichotomous factor (presence of transient dam-foal pairs vs absence of transient dam-foal pairs).

Data analyses—The crude measure of association between a single putative risk factor and being an affected farm 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.[47] Confidence limits for the bivariate ORs were derived by use of maximum-likelihood estimators.[47] 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 as 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 having foals affected with *R equi* pneumonia at a value of $P < 0.15$ were included in multivariate analyses. Variables included in multivariate analyses 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, categories of farm size) with another (eg, categories of density of horses per acre). Coassociation was also examined by eliminating matching then applying frequency distribution calculations 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 limited number of farms studied, and considerable collinearity among covariates, multivariate models were constructed for variables that related to horse breed, acreage, and size and characteristics of the horse population. By use of multiple conditional logistic regression[47] models, estimates of the magnitude and direction of the association of a farm having foals that develop *R equi* pneumonia with factors selected from bivariate analyses were obtained. Also, estimates for single variables were adjusted for the effects of other variables associated with a farm being affected. For multivariate analyses, 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 applying a likelihood ratio χ^2 test; a value of $P < 0.10$ was required for a variable to be entered (selection steps) in the model, and $P > 0.15$ was selected as the cutoff for removal (backward elimination steps).[47] 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.[47] Variables selected for inclusion in a final multivariate model were considered factors that best predicted development of *R equi* pneumonia in foals on a farm. All possible bivariate interactions among main effects variables that were significantly associated with a farm being affected with *R equi* were examined. Conditional logistic regression analyses were conducted by use of a commercially available statistical program.[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 eliminated from the modeling procedure.

Results

Of 82 veterinarians that originally agreed to participate, 32 provided complete data from 1 matched set of a control and an affected farm. Farms from 33 counties in Texas were studied, representing geographically diverse regions of the state.

Number of years farm used for raising horses and foals—Number of years that the farm had been used for raising horses was recorded for all 64 farms. There was no significant difference between affected farms (median, 13.5 years; range, 2 to 127 years) and control farms (median, 10 years; range, 2 to 127 years). When this variable was examined categorically (≤ 15 or > 15 years), there still was no significant difference. The distribution of the number of years that a farm had been used for raising foals < 6 months of age was similar for affected farms (median, 13 years; range, 2 to 127 years) and control farms (median, 10 years; range, 1 to 127 years). When this variable was considered categorically (≤ 15 or > 15 years), there was no significant difference between control and affected farms.

Number of foals that developed *R equi* pneumonia during 1997—Number of foals that developed *R equi* pneumonia was recorded for all farms. On the 32 control farms, no foals were affected. A total of 113 foals on the 32 affected farms developed *R equi* pneumonia. Median number of affected foals on the 32 affected farms was 1.5 foals (range, 1 to 15 foals). Median percentage of foals on affected farms that developed *R equi* pneumonia was 6.6% (range, 1.3 to 100%). Of the 32 affected farms, 12 (37.5%) had < 5% of foals affected, 8 (25.0%) had 5 to 10% of foals affected, 4 (12.5%) had 11 to 20% of foals affected, 7 (21.9%) had 21 to 50% of foals affected, and 1 (3.1%) had 100% of foals affected. For at least 1 foal on all 32 affected farms, the diagnosis of *R equi* pneumonia was based on the presence of clinical signs of pneumonia and isolation of *R equi* from either a transtracheal aspirate specimen or lung tissue specimens obtained at necropsy.

Number of foals that died or were euthanatized as a result of developing *R equi* pneumonia during 1997—No foals on the control farms died or were euthanatized because of *R equi* pneumonia. All affected foals on the affected farms were classified as either completely recovered from pneumonia or as having died or been euthanatized because of pneumonia. Thirty-three (29.2%) of the 113 affected foals on the 32 affected farms died or were euthanatized because of *R equi* pneumonia. Of the 32 affected farms, the median number of foals that died or were euthanatized because of *R equi* pneumonia was 1 foal/farm (range, 0 to 4 foals/farm). The median case fatality rate on affected farms was 25% (range, 0 to 100%). The case fatality rate was 0 to 25% for 17 (53.1%) farms, 26 to 50% for 8 (25%) farms, 51 to 75% for 2 (6.3%) farms, and 100% for 5 (15.6%) farms. The median number of foals that made a complete recovery from *R equi* pneumonia on affected farms was 1 foal/farm (range, 0 to 15 foals).

Prevalence of *R equi* pneumonia on affected farms in previous years—On the 32 control farms, no foals were affected with *R equi* pneumonia during the years 1994, 1995, and 1996. On the 32 affected farms, prevalence of *R equi* pneumonia in 1996 was 0% for 11 (34.4%) farms, 1 to 5% for 15 (46.9%) farms, 6 to 10% for 4 (12.5%) farms, 11 to 20% for 1 (3.1%) farm, and > 50% for 1 (3.1%) farm. Prevalence of *R equi* pneumonia in 1995 was reported for 27 affected farms; prevalence was 0% for 8 (29.6%) farms, 1 to 5% for 14 (51.9%) farms, 6 to 10% for 3 (11.1%) farms, and > 50% for 2 (7.4%) farms. Prevalence of *R equi* pneumonia in 1994 was reported for 23 affected farms; prevalence was 0% for 9 (39.1%) farms, 1 to 5% for 11

(47.8%) farms, 6 to 10% for 1 (4.3%) farm, 11 to 20% for 1 (4.3%) farm, and 31 to 50% for 1 (4.3%) farm.

Number of foals that died or were euthanatized for reasons other than development of *R equi* pneumonia—On the 32 affected farms, a median of 0.5 foals (range, 0 to 6 foals) died or were euthanatized for disorders other than *R equi* pneumonia, compared with a median of 1 foal (range, 0 to 10 foals) on control farms. The median percentage of all foal deaths caused by disorders other than *R equi* pneumonia (number of foals that died or were euthanatized for reasons other than *R equi* pneumonia/total foal deaths) was 50% (range, 0 to 100%) for affected farms and 100% for control farms.

Predominant breed—In relation to Quarter Horses (the reference category), affected farms were significantly less likely than control farms to have horses categorized as other breeds (**Table 1**).

Acreage of farm—The total acreage of affected farms (median, 112.5 acres; range, 5 to 250,000 acres) was larger than that of control farms (median, 62.5 acres; range, 7 to 250,000 acres). When total acreage was examined categorically (< 90 acres, 90 to 200 acres, and > 200 acres), farms with 90 to 200 acres and farms with > 200 acres were significantly associated with increased risk of *R equi* pneumonia, compared with farms with < 90 acres (Table 1).

The acreage used in the husbandry of horses on affected farms (median, 84.5 acres; range, 5 to 3,000 acres) was greater than acreage used on control farms (median, 45 acres; range, 5 to 3,000 acres). When this variable was examined categorically (farms < 60 or ≥ 60 acres), farms that used ≥ 60 acres in the husbandry of horses were significantly associated with increased risk of *R equi* pneumonia in foals.

Number and density of horses and foals on the farm—There were 9,991 horses on the 64 farms. There were 7,042 horses on the 32 affected farms and 2,949 horses on the 32 control farms. The number of horses on affected farms (median, 85 horses; range, 5 to 1,100 horses) was greater than that of control farms (median, 51.5 horses; range, 2 to 1,100 horses). When this variable was examined categorically (≤ 160 or > 160 horses), farms with > 160 horses were significantly associated with increased risk of *R equi* pneumonia in foals (Table 1).

There were 2,764 foals on the 64 farms. The number of foals on affected farms (median, 27.5 foals; range, 1 to 260 foals) was greater than that of control farms (median, 10 foals; range, 1 to 124 foals). When this variable was examined categorically (≤ 17 or > 17 foals), farms with > 17 foals were significantly associated with increased risk of *R equi* pneumonia in foals.

The density of horses on affected farms (median, 1.1 horses/acre; range, 0.1 to 12 horses/acre) was similar to that of control farms (median, 1.0 horses/acre; range, 0.01 to 40 horses/acre). When this variable was examined categorically (≤ 1.75 or > 1.75 horses/acre), there was no significant difference between control and affected farms.

Foal density on affected farms (median, 0.4 foals/acre; range, 0.03 to 3.06 foals/acre) was greater than that of control farms (median, 0.2 foals/acre; range, 0.01 to 10 foals/acre). When this variable was examined categorically (≤ 0.25 or > 0.25 foals/acre), farms with > 0.25 foals/acre were significantly associated with increased risk of *R equi* pneumonia in foals.

Percentage of dam-foal pairs that were transient or resident—The percentages of transient dam-foal pairs on the farms were consolidated and examined categorically (ie, presence of transient dam-foal pairs vs no transient dam-foal pairs). Affected farms were significantly more likely to have transient dam-foal pairs on the farm (Table 1). The percentages of resident dam-foal pairs on the farms were consolidated and examined categorically (< 75 or ≥ 75%); control farms were significantly more likely to have ≥ 75% of the dam-foal pairs permanently housed on the farm.

Number of resident mares—The number of resident mares on affected farms (median, 16.5 mares; range, 0 to 63 mares) was greater than that of control farms (median, 11 mares; range, 0 to 138 mares). When this variable was examined categorically (< 10 or ≥ 10 mares), affected farms were significantly more likely to have ≥ 10 resident mares than were control farms (Table 1). There was no significant difference in the number of resident maiden mares between affected farms (median, 3 mares; range, 0 to 12 mares) and control farms (median, 1 mare; range, 0 to 20 mares). There was no significant difference in the number of resident barren mares between affected farms (median, 2 mares; range, 0 to 23 mares) and control farms (median, 2 mares; range, 0 to 12 mares). The number of resident dam-foal pairs on affected farms (median, 14.5 dam-foal pairs; range, 0 to 37 dam-foal pairs) was greater than that of control farms (median, 6 dam-foal pairs; range, 0 to 124 dam-foal pairs). When this variable was examined categorically (< 10 resident dam-foal pairs or ≥ 10 resident dam-foal pairs), affected farms were significantly more likely to have ≥ 10 resident dam-foal pairs than were control farms.

Age of resident mares—The number of resident mares < 5 years old on affected farms (median, 3 mares; range, 0 to 14 mares) was not significantly different from that of control farms (median, 1 mare; range, 0 to 30 mares). The number of resident mares 5 to 10 years old on affected farms (median, 6.5 mares; range, 0 to 30 mares) was not significantly different from that of control farms (median, 5 mares; range, 0 to 40 mares). The number of resident mares 11 to 15 years old on affected farms (median, 5 mares; range, 0 to 23 mares) was not significantly different from that of control farms (median, 2.5 mares; range, 0 to 45 mares). The number of resident mares ≥ 16 years old on affected farms (median, 3 mares; range, 0 to 23 mares) was not significantly different from that of control farms (median, 1.5 mares; range, 0 to 33 mares).

Number of transient mares—The number of maiden transient mares on affected farms (median, 1 mare; range, 0 to 70 mares) was not significantly different from that of control farms (median, 0 mares; range, 0 to 35 mares). The number of barren transient mares on affected farms (median, 0 mares; range, 0 to 288 mares) was

Table 1—Comparison of variables, using bivariate conditional logistic regression, between 32 equine breeding farms on which foals developed *Rhodococcus equi* pneumonia and 32 control farms

Variable	*R equi* No. (%)	Control No. (%)	Odds ratio	95% CI	*P* value
Predominant breed					
Quarter Horse	20 (62.5%)	14 (43.8%)	1	NA	NA
Thoroughbred	6 (18.8%)	6 (18.8%)	0.36	0.03, 3.92	0.403
Other breeds	2 (6.3%)	8 (25.0%)	0.17	0.03, 1.05	0.056
Arabian	4 (12.5%)	4 (12.5%)	0.58	0.12, 2.86	0.507
Total farm acreage					
< 90 acres	11 (34.4%)	21 (65.6%)	1	NA	NA
90 to 200	10 (31.3%)	7 (21.88%)	4.17	0.88, 19.83	0.073
> 200 acres	11 (34.4%)	4 (12.5%)	18.33	1.67, 201.75	0.018
Acreage used for husbandry					
< 60 acres	11 (34.4 %)	19 (59.4%)	1	NA	NA
≥ 60 acres	21 (65.6%)	13 (40.6%)	3.00	0.97, 9.30	0.057
No. of horses					
≤ 160	20 (62.5%)	28 (87.5%)	1	NA	NA
> 160	12 (37.5%)	4 (12.5%)	9.00	1.14, 71.04	0.037
No. of foals					
≤ 17	11 (34.4%)	21 (67.7%)	1	NA	NA
> 17	21 (65.6%)	10 (32.3%)	6.50	1.47, 28.80	0.014
Horse density (horses/acre)					
≤ 1.75	22 (68.8%)	26 (81.3%)	1	NA	NA
> 1.75	10 (31.3%)	6 (18.7%)	2.00	0.60, 6.64	0.258
Foal density (foals/acre)					
≤ 0.25	12 (37.5%)	20 (62.5%)	1	NA	NA
> 0.25	20 (62.5%)	12 (37.5%)	10.00	1.28, 78.12	0.028
Transient dam-foal pairs					
0%	10 (32.3%)*	20 (62.5%)	1	NA	NA
> 0%	21 (67.7%)*	12 (37.5%)	5.55	1.22, 25.00	0.027
Resident dam-foal pairs					
< 75%	17 (53.1%)	6 (18.8%)	1	NA	NA
≥ 75%	15 (46.9%)	26 (81.2%)	0.15	0.03, 0.68	0.014
No. of resident dam-foal pairs					
< 10	10 (31.3%)	19 (61.3%)*	1	NA	NA
≥ 10	22 (68.8%)	12 (38.7%)*	5.50	1.22, 24.81	0.027
No. of resident mares					
< 10	8 (25.0%)	15 (48.4%)*	1	NA	NA
≥ 10	24 (75.0%)	16 (51.6%)*	2.75	0.88, 8.64	0.083
No. of transient dam-foal pairs					
0	11 (35.5%)*	21 (67.7%)*	1	NA	NA
≥ 1	20 (64.5%)*	10 (32.3%)*	10.00	1.28, 76.92	0.028
No. of transient mares					
0	11 (35.5%)*	21 (67.7%)*	1	NA	NA
≥ 1	20 (64.5%)*	10 (32.3%)*	10.00	1.28, 76.92	0.028
No. of transient mares that foaled on the farm					
< 5	16 (51.6%)*	25 (80.7%)*	1	NA	NA
≥ 5	15 (48.4%)*	6 (19.3%)*	9.00	1.14, 71.04	0.037
< 10	18 (58.1%)*	27 (87.1%)*	1	NA	NA
≥ 10	13 (41.9%)*	4 (12.9%)*	5.00	1.10, 22.82	0.038
No. of transient mares that foaled off farm					
< 5	17 (54.8%)*	26 (83.9%)*	1	NA	NA
≥ 5	14 (45.2%)*	5 (16.1%)*	5.00	1.10, 22.82	0.038

*Data from 31 farms.
CI = Confidence interval. NA = Not applicable (referent category).

not significantly different from that of control farms (median, 0 mares; range, 0 to 30 mares). The number of transient dam-foal pairs on affected farms (median, 5 dam-foal pairs; range, 0 to 260 dam-foal pairs) was significantly greater than that of control farms (median, 0 dam-foal pairs; range, 0 to 83 dam-foal pairs). When this variable was examined categorically (0 or ≥ 1 transient dam-foal pairs), affected farms were significantly more

likely to have at least 1 transient dam-foal pair than were control farms (Table 1). The number of transient mares on affected farms (median, 5 mares; range, 0 to 490 mares) was significantly greater than that of control farms (median, 0 mares; range, 0 to 120 mares). When this variable was examined categorically (0 or ≥ 1 transient mares), affected farms were significantly more likely to have ≥ 1 transient mares than were control farms.

Number of transient mares that foaled on the farm or elsewhere—The number of transient mares that delivered foals on the farm was greater for affected farms (median, 4 mares; range, 0 to 125 mares) than for control farms (median, 0 mares; range, 0 to 26 mares). When this variable was examined categorically (< 5 or ≥ 5 mares), affected farms were significantly more likely to have ≥ 5 transient mares that delivered foals on the farm (Table 1). When this variable was further examined categorically (< 10 or ≥ 10 mares), affected farms were significantly more likely to have ≥ 10 transient mares that delivered foals on the farm.

The number of transient mares that delivered their foal at another facility was greater for affected farms (median, 3 mares; range, 0 to 210 mares) than for control farms (median, 0 mares; range, 0 to 75 mares). When this variable was examined categorically (< 5 or ≥ 5 mares), affected farms were significantly more likely to have ≥ 5 transient mares that delivered their foal at another farm.

Multivariate modeling—Variables used in a multiple variable model-building strategy included predominant breed, size of the farm (90 to 200 acres and > 200 acres, relative to < 90 acres), number of acres used in the husbandry of horses (≥ 60 vs < 60 acres), total number of horses on the farm (> 160 vs ≤ 160 horses), number of foals on the farm (> 17 vs ≤ 17 foals), density of horses on the farm (≤ 1.75 > 1.75 horses/acre), density of foals on the farm (> 0.25 vs ≤ 0.25 foals/acre), presence of transient dam-foal pairs on the farm, proportion of resident dam-foal pairs on the farm (≥ 75% vs < 75%), number of resident dam-foal pairs (< 10 vs ≥ 10), number of resident mares (< 10 vs ≥ 10), number of transient dam-foal pairs (0 vs ≥ 1), number of transient mares that delivered their foal on the farm (< 5 vs ≥ 5), number of transient mares that delivered their foal at another farm (< 5 vs ≥ 5), and number of transient mares (0 vs ≥ 1).

Variables selected for the final multivariate model included size of the farm (> 200 acres), proportion of dam-foal pairs that were resident (≥ 75%), and number of resident dam-foal pairs (≥ 10; **Table 2**). Compared with control farms, affected farms were significantly more likely to be > 200 acres in total size, were significantly more likely to have ≥ 10 resident dam-foal pairs, and were significantly less likely to have ≥ 75% of dam-foal pairs as resident dam-foal pairs. No significant bivariate interactions were detected, and no values were considered extreme on the basis of visual examination of goodness-of-fit plots.

Table 2—Variables identified, using stepwise multiple conditional logistic regression, as significantly ($P < 0.05$) associated with the development of *R equi* pneumonia in foals on 32 affected and 32 control equine breeding farms

Variable	Odds ratio	95% CI	*P* value
Size of farm > 200 acres	96.24	1.01, 9186.67	0.045
≥75% resident dam-foal pairs	0.07	0.008, 0.660	0.020*
≥ 10 resident dam-foal pairs	23.21	1.49, 361.37	0.025

*Farms with affected foals were less likely to have ≥ 75% resident dam-foal pairs, compared with control farms.

Discussion

In our study, criteria for identifying an affected foal were selected to accommodate variability among veterinarians in methods of diagnosing *R equi* pneumonia. Variability in diagnostic methods resulted from variations in practitioner expertise and experience, availability of radiographic and sonographic equipment, availability of clinicopathologic and microbiologic services, individual preferences of the owners and veterinarians, economic considerations, and other reasons. The possibility of misdiagnosis existed, although we do not believe this happened frequently. Foals < 3 or > 24 weeks of age that developed pneumonia were not considered affected foals, because *R equi* pneumonia is uncommon in foals of those age groups.[3-5]

Data were provided for matched pairs of farms by 32 veterinarians who were involved in equine practice in Texas. Matched affected and control farms were located in the same county or counties adjacent to each other to minimize the effect of geographic differences between affected and control farms. Geographic factors may contribute to increased risk for development of *R equi* pneumonia in foals in Texas, but a study of different design would be required to detect this.

Limitations of our study were attributable to study design. The accuracy and reliability of data provided were determined by the efforts and knowledge of participating veterinarians. Another limitation of this study was the small sample size. Data were obtained from 32 affected farms and 32 paired control farms, representing a population of 2,764 foals and nearly 10,000 horses overall. Although this number of farms exceeds other reports in the literature, it is a small number of farms. Because of the small sample size, some ORs had wide 95% confidence intervals. This must be given consideration when interpreting these data, particularly results of the multivariate analyses. Studies involving larger populations of equine breeding farms would overcome this sample size limitation. Another limitation was that this study was performed on farms in Texas, and findings may not be appropriate for extrapolation to other regions. Moreover, because of the case-control design of this study, the reference population of farms from which the study farms were selected was not known. Despite these limitations, we believe the results of this study provide useful information for veterinarians and horse owners about farm characteristics that are associated with increased risk for the development of *R equi* pneumonia in foals.

Many variables that were significantly associated with development of *R equi* pneumonia in the bivariate analyses but that were not retained in the multivariate model may be important risk factors nevertheless. Significant associations were detected among many of

these variables and with covariates that were retained in the final multivariate model, possibly diluting or obscuring the strength of the observed bivariate association because of coassociation. Thus, it is possible that many of the variables identified in bivariate analyses were as important as those that remained significant in the multivariate analysis. For example, the number of resident mares that foaled on the farm was significantly associated with the number of foals on the farm and with foal density. Consequently, foal density and number of foals were probably important, although multivariate models using the number of resident mares that foaled on the farm were statistically superior. Similarly, the proportion of resident mares and absence of transient mares were significantly coassociated; the former covariate was statistically superior in multivariate modeling.

No significant difference between control and affected farms in the number of years that farms had been used for raising horses or foals was found. This finding was in contrast to that of a previous report[27] that examined 5 farms in Canada. In that study, a farm that had been used in the husbandry of horses for 30 years had greater pasture and paddock contamination with *R equi* than did 2 farms that had housed horses for 4 and 6 years. Also in that report, there was significant correlation between *R equi* contamination of the stables, paddocks, and pastures and duration that farms had been used in the husbandry of horses. Those authors suggest, and there is a widely-held clinical belief, that there is progressive accumulation of *R equi* in the soil over time on horse farms; thus, there is increased risk of foals developing *R equi* pneumonia on farms that have housed horses for many years.[27] In our study, we did not perform quantitative bacteriologic cultures to assess environmental contamination; however, data from these 64 farms did not support the hypothesis that prolonged use of a farm for raising horses significantly increased the risk for development of *R equi* pneumonia in foals.

There remains a paucity of information in the literature regarding prevalence of *R equi* pneumonia in foals on equine breeding farms. It is frequently stated that *R equi* pneumonia is endemic on some farms, is sporadic on others, and does not occur on most[3,4,36]; however, there are few data to demonstrate the actual prevalence of *R equi* pneumonia on individual farms. On 32 affected farms studied in 1997, the median percentage of foals that developed *R equi* pneumonia was 6.6%. Twenty (62.5%) farms had > 5% of foals affected, and 12 (37.5%) had > 10% of foals affected. Eight (25%) farms had > 20% of foals affected. Pneumonia in foals caused by *R equi* appears to be of great concern and warrants improved methods of prevention and early diagnosis at farms where the prevalence exceeds 5%.

In previous reports, data regarding mortality rates for foals with *R equi* pneumonia are largely based on retrospective reports from university veterinary teaching hospitals; such mortality rate data may differ from that obtained directly from affected farms. Hospital data are likely to include biases arising from economic value of foals, severity of disease, and familiarity of referring veterinarians with this disease. Also, some foals develop *R equi* pneumonia and die suddenly on the farm, prior to recognition of clinical signs; such foals are unlikely to be examined at a veterinary teaching hospital. Previous studies,[44,48] conducted prior to the routine use of erythromycin and rifampin for treatment, cite mortality rates ≤ 80% for foals with *R equi* infection. At veterinary teaching hospitals, mortality rates for affected foals of 51% (20/39)[18] and 58% (28/48)[19] are reported; with treatment with erythromycin and rifampin, a mortality rate of 12% (7/57)[22] was observed. At our university hospital, we reported a mortality rate of 41% (25/61) for foals that developed *R equi* pneumonia.[6] Ainsworth et al[16] reported a mortality rate of 28% (32/115) among Standardbred and Thoroughbred foals admitted to 6 university teaching hospitals. On a Thoroughbred breeding farm in New South Wales, a mortality rate of 42% (8/19 foals) was reported.[49] In the study reported here, the overall case fatality rate was 29.2% for 113 affected foals. On our 32 affected farms, the median case fatality rate was 25% (range, 0 to 100%). Case fatality rate was > 50% for 22% (7/32) of affected farms. On affected farms, the median percentage of all foal deaths associated with *R equi* pneumonia was 50%. These data indicate that on affected farms, *R equi* represents a major cause of foal deaths.

Acreage of the farm was significantly associated with *R equi* pneumonia. In the bivariate analyses, large farms (farms that used ≥ 60 acres in the husbandry of horses) were approximately 3 times as likely to have foals that developed *R equi* pneumonia, compared with smaller farms. Similarly, farm size of < 90 acres was associated with decreased risk of having affected foals. The OR increased with acreage, indicating that the greater the acreage, the greater the risk. In the multivariate analyses, farms with > 200 acres were considerably more likely to have foals that developed *R equi* pneumonia. Because many horse breeding farms congregate the horses on portions of the farm, we believe the acreage used in the husbandry of horses more accurately represents the risk factor than does total farm acreage. Farm acreage was closely associated with the number of horses and foals; thus, the increased risk may relate to size of horse population.

There were numerous variables regarding the number and density of horses and foals that represented increased risk for development of *R equi* pneumonia in foals. Farms with > 160 horses and farms with > 17 foals were at higher risk of *R equi* foal pneumonia. Farms with foal densities > 0.25 foals/acre were approximately 10 times as likely to have affected foals as were farms with ≤ 0.25 foals/acre. *Rhodococcus equi* is commonly found in the feces of mares and foals. The organism can replicate in the intestinal tract of foals ≤ 3 months of age[39]; the greater the foal population, the greater the contamination of the environment with feces.[2] Foals are further exposed to the microorganism when environmental contamination is increased via feces of mature horses.[33] In our study, the density of horses on the farm was not associated with increased risk for development of *R equi* pneumonia in foals, but the density of foals on the farm was associated with increased risk. The importance of this finding is unknown. Farms with high foal density

may be at greater risk because foals are the population at risk for development of *R equi* pneumonia, or foals may represent a source of greater environmental contamination that results in more exposure of other foals to the organism. On farms with a high density of breeding horses and where *R equi* pneumonia is endemic, reduction of foal density should be considered to help minimize the impact of this disease.

The presence and number of transient dam-foal pairs on the farm were associated with increased risk for development of *R equi* pneumonia in foals. In bivariate analyses, affected farms were approximately 10 times as likely to have transient dam-foal pairs as were control farms. Regardless of whether the transient mares delivered their foals on the farm or elsewhere, their presence on the farm was associated with increased risk for *R equi* pneumonia. Breeding farms with large horse populations and high densities of mares and foals are perhaps more likely to include transient mares and foals. Alternatively, infected transient mares and foals may be a source of virulent *R equi* for resident foals.

Farms with ≥ 10 resident mares and ≥ 10 resident dam-foal pairs were at greater risk for foals developing *R equi* pneumonia than were farms with fewer horses in these categories. This finding emphasizes the importance of large mare and foal populations as risk factors for this disease. The age of the mares (resident or transient) on the farm did not appear to alter the risk for development of *R equi* pneumonia in foals, nor did the proportion of maiden and barren mares (resident or transient).

Results of this study indicate that there are specific farm characteristics associated with increased risk for development of *R equi* pneumonia in foals. Important characteristics of note include farms of large acreage; large numbers of horses, mares, and foals; high foal density; and presence of transient mares and their foals.

[a]SAS/STAT, SAS Institute Inc, Cary, NC.

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