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Preventive Veterinary Medicine 34 (1998) 31–46

PREVENTIVE VETERINARY MEDICINE

Associations between passive immunity and morbidity and mortality in dairy heifers in Florida, USA

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Accepted 7 July 1997

Abstract

A prospective cohort study was undertaken to determine calf-level factors that affected calf health status between birth and 6 months of age. A convenience sample of approximately 3300 female Holstein calves born in 1991 on two large Florida dairy farms was used for the study. Data collected on each calf at birth included farm of origin, weight, height at the pelvis, birth date, and serum total protein (a measure of colostral immunoglobulin absorption). Birth season was dichotomized into summer and winter using meteorological data collected by University of Florida Agricultural Research Stations. Health data including date of initial treatment and number of treatments were collected for the diseases diarrhea, omphalitis, septicemia and pneumonia. All calves were followed for 6 months. Cumulative incidences of mortality and occurrence of diarrhea, omphalitis, septicemia and pneumonia were 0.12, 0.35, 0.11, 0.24 and 0.21, respectively. Serum total protein (TP) was a significant risk factor for mortality. The association of TP and mortality was quadratic and showed a dramatic decrease in mortality as TP increased from 4.0 to 5.0 g/dl, a small improvement from 5.0 to 6.0 g/dl and virtually no improvement in mortality rates as TP increased over 6.0 g/dl. The hazard mortality ratio was constant from birth to six months, indicating that the increased risk of mortality associated with low levels of TP was evident through six months of age. No interactions between TP, farm, season, or birth weight were found in these analyses. Serum total protein concentration was a significant risk factor for the

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PII S0167-5877(97)00060-3

occurrences, age of onset and severity of septicemia and pneumonia. The association between TP and septicemia was linear and an interaction with birth season was found. The association between TP and pneumonia was quadratic, and in contrast to the TP-and-septicemia relationship, the morbidity hazard ratio for pneumonia was not constant over the time measured; that is, colostral immunity protected the calf from developing pneumonia early in life, but this effect disappeared as the calf got older. Total protein was not a significant risk factor for diarrhea or omphalitis.

Keywords: Cattle-morbidity and mortality; Passive immunity; Immunology

1. Introduction

Successful dairy-replacement rearing is dependent upon a multitude of complex, interrelated factors of which colostrum management is but one. The neonatal calf, which is born with little or no humoral immunity, is totally dependent upon absorption of colostrally-derived immunoglobulins for its early disease resistance (Tizard, 1996; Duhamel and Osburn, 1984). A 2- to 4-fold increase in mortality in calves with failure of passive transfer (FPT) compared to those that have received adequate amounts of colostral immunoglobulins has been reported (McEwan et al., 1970; Boyd, 1972; McGuire et al., 1976; Caldow et al., 1988; Robison et al., 1988).

The protective effects of colostrum in relation to the incidence and severity of neonatal septicemia and early calfhood pneumonia are well established (Davidson et al., 1981; Fallon et al., 1987; Howard et al., 1989; Belknap et al., 1991). Davidson et al. (1981) found that not only was respiratory disease risk reduced and fewer treatment days required in colostrum-satisfied calves, but onset of disease was delayed by 5 to 7 days.

With respect to neonatal calf diarrhea, the effects of passive immunity are less clear. Results of epidemiological and experimental studies are divided between those showing no effect (McEwan et al., 1970; Caldow et al., 1988; Harp et al., 1989) and those demonstrating a reduction in incidence and severity of diarrhea and/or a decrease in mortality attributable to enteritis (Boyd et al., 1974; Naylor et al., 1977; Fallon et al., 1987). These discrepancies can be explained mainly by differences in the primary causative organism involved. Diarrhea caused by *Escherichia coli* can be effectively controlled by feeding the neonate colostrum containing antibodies directed specifically at the enterotoxigenic form (Boyd et al., 1974; Logan et al., 1974). Colostral antibodies are not as efficacious against enteritis caused by *Salmonella* sp., viruses and protozoa—probably due to the later age at which these disease problems occur (Smith et al., 1980; Archambault et al., 1989; Harp et al., 1989).

The most commonly-used methods for assessing passive transfer status in the calf are radial immunodiffusion (RID), zinc sulfate turbidity (ZST) and serum total protein (TP) determined by refractometry. The RID is considered the gold standard against which all others are measured (Curtis et al., 1986). It is generally accepted that calves with serum immunoglobulin G1 (IgG1) concentrations of less than 10 mg/ml have failure of passive transfer (FPT) (Gay, 1983). Serum total protein concentration is highly correlated ($r = 0.88$) with immunoglobulin concentrations measured using RID (Naylor and

Kronfeld, 1977). Braun and Tennant (1983) described three disease risk categories based on the calf's serum total protein values at 24–48 h. Calves were at high risk of mortality with TP < 5.0 g/dl, low risk of mortality with TP > 5.4 and at intermediate risk if TP was between 5.0 and 5.4.

The objective of this study was to define the associations between passive immune status (as determined by serum total protein) and morbidity and mortality during the first six months of life. A secondary objective was to provide descriptive epidemiologic data of morbidity and mortality in a large population of dairy calves.

2. Materials and methods

2.1. Study population

Data were from a convenience sample of two large dairy farms in Florida. One farm (Barn 1), in north-central Florida, consisted of approximately 3000 adult animals and 2000 replacements. All cows were managed as one herd and milked through one large parlour. The second farm was located in south-central Florida and had approximately 6000 adult cows and 5000 replacement animals. This latter farm was operated as 5 distinct and separate units, each under separate and independent management. Four of these units were comprised either exclusively, or predominantly, of Holstein cows (study Barns 2, 3, 4 and 5). One was exclusively Jersey cattle and was not included in the study.

All heifer calves born from January 16, 1991 through January 15, 1992 were enrolled in the study. This cohort was used for descriptive epidemiology but only those that lived longer than 48 h and had serum total protein concentration determined were used for statistical analysis. Follow-up on all calves was for a full 6 months, unless the calf died or was sold.

2.2. Dry cow and colostrum management

Dry-cow and colostrum management was essentially the same in each of the 5 barns. Within 21 days of calving, dry cows were placed on large pastures with artificial and/or natural shade provided. Cows were monitored for calving-related problems at least every 2–3 h and intervention applied when necessary. Calves were fed 2 to 3 l of colostrum via esophageal tube feeder within 3 to 6 h of birth. Calves were picked up from the maternity lot twice daily and taken to the calf-rearing area of the farm.

Colostrum was collected in a similar manner in all barns. Cows were milked within 12 h of parturition into individual cans and the quality determined using a colostrometer and a variation of the methods of Fleenor and Stott (1980). Only colostrum with colostrometer Ig readings of greater than 50 mg/ml was used for feeding of calves during the first 24 h.

2.3. Calf housing and management

Barn 1 calves were housed individually in 2.5 m × 1.5 m calf hutches. Calves from Barns 2–5 were transported to a common calf-rearing facility where they were housed individually in either 2.5 m × 1.5 m calf hutches or an open-sided calf barn with 1.25 m × 1 m elevated stalls. Milk and grain feeding, vaccination and deworming practices were similar between the two farms (5 barns).

2.4. Birth data collection

Birth data were collected within the first 8 days of life. Birth weight was obtained using a platform scale (Terraillon, Versailles, France) accurate to ± 0.9 kg. Body weights collected at 5 to 7 days of age were adjusted to be comparable to those taken at 0 to 4 days of age using the following formula:

$$\mathrm{ABW} = W57 - 0.75\,kg$$

where ABW = adjusted birth weight in kg and $W57$ = body weight taken at 5 to 7 days of age. This formula was determined by weighing a subset of study calves ($n = 58$) at 1 to 4 days of age and again 3 days later. Paired *t*-test showed a 0.75 kg difference in the two weighs ($P < 0.01$).

Blood samples were collected via jugular venipuncture into evacuated tubes (Vacutainer®, Becton Dickinson, Rutherford, NJ, USA) between 2 and 8 days-of-age. Blood was placed on ice (4 to 8°C) immediately after collection and serum was separated within 24 h by centrifugation at 3000 *g* for 20 min. Serum total protein was determined using a refractometer (AO Scientific Instruments, Buffalo, NY, USA) as described by Reid and Martinez (1975).

2.5. Health and culling data collection

Calf morbidity, mortality and culling information were collected and recorded on a daily basis using on-farm database management software (Barn 1—VisiCow®, Haas Chemical, Mobile, AL, USA; Barns 2–5—DBase III®, Aston-Tate, Torrance, CA, USA). Morbidity data recorded included date of disease event, diagnosis made by trained farm personnel and treatment. Date and reason for death or disposal were recorded for deaths and culls.

2.6. Disease definitions

Farm personnel were trained by one of the investigators (GAD) using standardized diagnostic-treatment protocols to recognize and treat the most common calfhood diseases. The four disease conditions of interest, diarrhea, septicemia, omphalitis and pneumonia, were chosen by the investigators because they represent the most commonly diagnosed diseases in dairy calves. The only other diseases seen in this population were bloat ($n = 3$) and keratoconjunctivitis ($n = 7$); these were included in the data as 'non-events'. An incident of disease was considered when the criteria for the disease, as described in Table 1, were met. Diagnostic skills of farm personnel were monitored

Table 1
Definition of calf diseases diagnosed by farm personnel

Disease	Diagnostic definition	Analysis definition
Diarrhea (scours)	Diarrhea ± dehydration requiring treatment with diarrhea specific products (kaolin-pectate, neomycin, etc.) and/or electrolytes	Treated for 2 or more consecutive days or for a total of 3 or more treatment days (unless died on second day)
Septicemia	Weak calf, off feed, depressed, ± fever, ± diarrhea; less than 30 days-of-age at start of treatment; treat with recommended parenteral antibiotics ± electrolytes	Calf less than 30 days-of-age at start of treatment and treated with recommended antibiotics at least 2 consecutive days (unless died on second day); calves treated for navel infection that died were recorded as septicemia
Navel infection	Navel swollen or has abnormal discharge, no fever or other systemic signs; all navels are checked at 2–4 days of age; treat with recommended parenteral antibiotics ± local therapy	Treated for 2 or more consecutive days or for a total of 3 or more treatment days (if died, coded as septicemia)
Pneumonia (respiratory)	Weak calf, ± off feed, labored breathing, ± nasal discharge, fever; greater than 29 days-of-age; treat with recommended parenteral antibiotics ± electrolytes	Calf greater than 29 days-of-age at first treatment and treated with recommended antibiotics at least 2 consecutive days (unless died on second day)

closely by one investigator (GAD) and feedback was provided by assisting in diagnosis and treatment on a bi-weekly basis. Diagnoses were also confirmed by performing necropsies on calves that died the day before and the day of the bi-weekly farm visit; which was approximately 15% of calf deaths.

2.7. Definition of seasons

There are only two seasons of concern in the sub-tropical climate of Florida: Summer and winter. Meteorological data for 1991 were collected at two University of Florida, Institute of Food and Agricultural Sciences Agricultural Research Stations, each within 80 km of the two study sites. Summer was defined as beginning when the mean daily temperature for a 15-day period was above 25°C, which is the upper thermoneutral temperature, or comfort temperature, for dairy cattle and calves (Shearer and Beede, 1990). May 7 to September 23, and April 23 to October 7 were the summer seasons for Barn 1 and Barns 2 to 5, respectively.

2.8. Statistical analysis

All analyses were performed using SAS® statistical software (SAS Institute, 1989). Descriptive statistics and residual diagnostics were performed using Proc Freq and Proc Univariate procedures. Categorical response variables (morbidity and mortality) were analyzed for differences in occurrence of disease or death using multivariable logistic regression (Proc Logistic) and for differences in time of onset and proportional hazards using life-table analysis (Proc Lifetest) and Cox proportional-hazards (survival) analysis (Proc Phreg). The continuous variable (disease-specific treatment days) was analyzed using multiple linear regression and analysis of covariance (Proc GLM).

Variables considered for inclusion in the models are listed in Table 2. Because of the small number of possible predictors per model, all possible combinations of variables were evaluated and remained in the model if the Log likelihood χ^2 test or the partial F-test or multiple partial F-test was significant. Alpha was $P < 0.05$ in all models. A second-order polynomial of serum total protein was considered in each model after evaluation of the relationship between mortality and 0.5 g/dl groupings of TP from 4.0 to 8.0 g/dl demonstrated a decreasing curvilinear response. Multicollinearity between TP and TP^2 was reduced when necessary by use of the centering technique described by Glantz and Slinker (1990). First-order interaction was evaluated using cross-product terms of variables. Confounding was considered a problem when inclusion of a variable in the model changed a parameter estimate for any other variables in the model by $\pm 50\%$.

The fit of logistic models was assessed using the Hosmer–Lemeshow goodness-of-fit χ^2 statistic (Hosmer and Lemeshow, 1989). Intraherd correlation coefficients were calculated for each response variable using the methods described by Snedecor and Cochran (1980). The proportional hazards assumption was tested by introduction of a time-dependent covariant into the models.

Table 2
Variables considered for inclusion in logistic and linear regression, life table analysis and survival analysis

Variable name	Variable description
TP	Serum total protein (continuous variable, range 4.0–8.0 g/dl)
TP^2	Quadratic term for TP
Barn	Class variable (1–5) for barn
Season	Dichotomous variable for season of birth (1 = summer, 0 = winter)
Birth wt	Birth weight (continuous variable, range 15–60 kg)
DIA	Dichotomous variable for diarrhea (0 = not treated for diarrhea, 1 = treated for diarrhea)
NUMDIA	Treatment days for diarrhea (continuous variable, range 0–22 days)
SEP	Dichotomous variable for septicemia (0 = not treated for septicemia, 1 = treated for septicemia)
NUMSEP	Treatment days for septicemia (continuous variable, range 0–31 days)
PNU	Dichotomous variable for pneumonia (0 = not treated for pneumonia, 1 = treated for pneumonia)
NUMPNU	Treatment days for pneumonia (continuous variable, range 0–32 days)
NAV	Dichotomous variable for navel infection (0 = not treated for navel infection, 1 = treated for navel infection)
NUMNAV	Treatment days for navel infection (continuous variable, range 0–17 days)

3. Results

3.1. Descriptive statistics

During the year-long assignment period, 3287 calves were born of which 3103 had complete morbidity, mortality, birth weight and serum total protein data. Four hundred and thirteen calves died during the first 6 months of life. Septicemia was the major disease-specific cause of death (Table 3). Case-fatality rates for diarrhea, septicemia and pneumonia were 7.7, 27.6 and 13.8%, respectively. Over 50% of mortality for which cause of death was listed as unknown occurred during the first 4 to 5 days of life.

The intraherd correlation coefficients for each of the outcome variables ranged from < 0.01 to 0.16 and are presented in Table 4.

3.2. Mortality

Failure of passive transfer is the true risk factor of interest but since TP is a good surrogate measure of FTP, it will be described as the risk factor. Serum TP is a significant risk factor contributing to mortality (Table 5). The non-linear protective

Table 3
Descriptive epidemiology of mortality in a cohort of calves born on 2 large dairy farms in FL, USA in 1991

	n	%
Total calves born alive	3287	–
Calves living > 48 h	3253	99.0[a]
Calves with complete data	3103	94.4[b]
Calf mortality before 180 days	379	11.7[b]
Calves culled before 180 days	142	4.4[b]
Calves born per barn[a]		
1	1134	34.5
2	726	22.1
3	734	22.3
4	551	16.8
5	142	4.3
Calves born per season[a]		
Summer	1314	40.0
Winter	1973	60.0
Disease-specific cause of death[c]		
Diarrhea	38	10.0
Septicemia	210	55.4
Pneumonia	83	21.9
Other	7	1.8
Unknown	41	10.8

[a]Percentages are of all calves born alive.
[b]Percentages are of calves living > 48 h.
[c]Percentages are of all deaths.

Table 4
Intraherd correlation coefficients (ICC) for mortality and four common calfhood diseases determined from 3103 Holstein heifer calves born in FL, USA in 1991

Variable	ICC
Mortality	< 0.01
Diarrhea	0.16
Omphalitis	0.13
Septicemia	0.07
Pneumonia	0.02

effect of absorbed colostral immunoglobulins can be seen in Fig. 1. The lowest risk was associated with TP ≥ 6.5 g/dl; this level will be considered baseline for future analyses. The Hosmer–Lemeshow goodness-of-fit test for this model was 6.96 (with 8 degrees of freedom, $P = 0.54$) which indicates that there was no reason to suspect that this model did not adequately fit the data.

Occurrence of septicemia and navel infection were also significant predictors of risk of mortality. Calves diagnosed with septicemia were 6 times (OR = 6.04, 95% confidence intervals [CI] = 4.66, 7.82) more likely to die than calves not having septicemia and navel infection increased the risk of mortality over 2-fold (OR = 2.35, 95% CI = 1.63, 3.38). Occurrence of diarrhea and pneumonia were not significant risk factors for mortality in this model.

In the proportional-hazards model (Table 5), the hazard of mortality associated with low TP was both significant and constant through 180 days of age using the three serum total protein groupings described by Braun and Tennant (1983) (Fig. 2).

Table 5
Final models of the associations between serum total protein (TP) and calf mortality through the first six months of age (3103 Holstein heifer calves, FL, USA, 1991)

	Logistic-regression model		Proportional-hazards model	
	Coefficient	P-value	Coefficient	P-value
Intercept	7.32	< 0.01	[a]	
TP	−3.00	< 0.01	−2.39	< 0.01
TP^2	0.22	< 0.01	0.18	0.02
Barn	[b]	0.04	[b]	0.04
Septicemia[c]	1.80	< 0.01	1.59	< 0.01
Navel[c]	0.85	< 0.01	0.85	< 0.01
(Time × TP, Time × TP^2)[d]	[a]		[b]	0.46
Hosmer–Lemeshow χ^2	$P > 0.50$		[a]	

[a] Not applicable.
[b] Multiple parameter estimates.
[c] Occurrence of septicemia and navel infection.
[d] Log likelihood χ^2 of inclusion of time-dependent covariates (i.e. interaction terms Time × TP and Time × TP^2) that is not significant indicates the assumption of constant proportional hazards over time is appropriate.

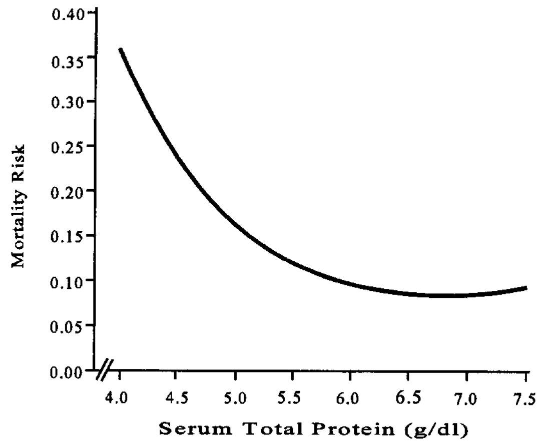

Fig. 1. The model-adjusted association between serum total protein and mortality risk in 3103 Holstein dairy heifers born in FL, USA in 1991.

3.3. Morbidity

Serum concentration of absorbed colostral antibodies was not associated with incidence, age of onset or severity of diarrhea or omphalitis in these calves. However, the above-mentioned disease measures for septicemia and pneumonia during the first 6 months were strongly associated with TP (Table 6).

Serum total-protein concentration had a linear, protective effect on occurrence of septicemia that was more pronounced during the summer (Table 7). The hazard ratios of developing septicemia were constant over the time interval measured (birth to 45 days of age).

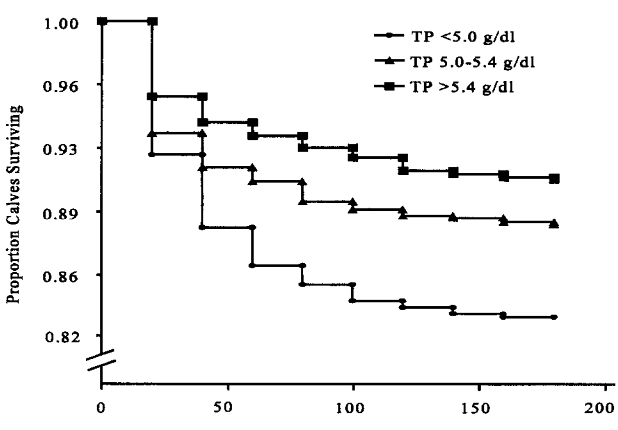

Fig. 2. The effects of serum total protein on the survival of Holstein heifer calves born in FL, USA in 1991.

Table 6
Statistical significance of the association between serum total protein and 4 calfhood diseases as measured by occurrence (yes/no), time of onset and duration of treatment

Parameter	Disease			
	Diarrhea	Septicemia	Navel Ill	Pneumonia
Logistic regression on occurrence of disease[a]	NS	< 0.01	NS	< 0.01
Cox regression analysis[a]	NS	< 0.01	NS	< 0.01
Duration of treatment[b]	NS	< 0.01	NS	0.02

[a] P-values determined from likelihood-ratio χ^2 test of the addition of TP or TP + TP^2 to the models.
[b] P-values determined from partial F-test of the addition of TP or TP + TP^2 to the models.

The same pattern of increased risk at lower TP was seen in the pneumonia model, although the odds ratios were somewhat lower and the relationship was quadratic in

Table 7
Parameter estimates and level of statistical significance of logistic regression (logistic-regression) and Cox proportional hazards (proportional-hazards) models of the associations between serum total protein and calf morbidity due to septicemia and pneumonia through the first six months of age

Variable	Septicemia		Pneumonia	
	Logistic-regression	Proportional-hazards	Logistic-regression	Proportional-hazards[a]
Intercept	0.22	[a]	6.70	
TP	−0.19*	−0.16*	−2.32**	−14.71*
TP^2	ns	ns	0.17**	1.08*
Barn	[b]	[b]	[b]	[b]
Season	ns	ns	−0.66**	−0.53**
Birth wt	−0.03**	−0.03**	ns	ns
TP × season[c]	−0.45**	−0.46**	ns	ns
Barn × season	[b]	[b]	[b]	[b]
Birth wt × season	0.05**	0.04**	ns	ns
(Time × TP, Time × TP^2)[d]	[a]	$P > 0.25$	[a]	$P < 0.05$
Hosmer–Lemeshow χ^2	$P > 0.50$		$P > 0.50$	
Odds ratio[c]				
TP (g/dl)	Winter		Summer	
4.0	1.50		4.74	
4.5	1.38		3.47	
5.0	1.27		2.54	
5.5	1.17		1.86	
6.0	1.08		1.37	
6.5	1.00		1.00	

Level of significance (*ns* = $P > 0.05$; * = $P < 0.05$; ** = $P < 0.01$).
[a] Not applicable.
[b] Multiple parameter estimates, $P < 0.05$; coefficients omitted for sake of brevity.
[c] Odds ratios of populations with varying serum total protein (TP) concentration in the two seasons.
[d] Log likelihood χ^2 of inclusion of 'time-dependent' covariates (i.e. interaction terms Time × TP and Time × TP^2) that is not significant indicates the assumption of constant proportional hazards over time is appropriate.

Table 8
Linear regression models of the relationship between serum total protein and natural logarithm of treatment days required for septicemia and pneumonia

Variable	Coefficient-septicemia	Coefficient-pneumonia
Intercept	2.08	2.18
TP	−0.10**	−0.10*
Barn	a	a
Season	ns	0.13*
Model R^2	0.04	0.05

Level of significance (ns = $P > 0.05$, * = $P < 0.05$; ** = $P < 0.01$).
[a]Multiple parameter estimates, $P < 0.05$; coefficients omitted for the sake of brevity.

nature (Table 7). The Cox proportional hazard regression model for the onset of pneumonia shows that FPT is a significant risk factor for earlier development of the disease when compared to calves receiving adequate colostral antibodies. Also, the hazard of developing pneumonia is not constant over time.

The number of treatment days for animals that had septicemia or pneumonia was significantly greater for those with lower TP, although the regression models accounted for only a very small proportion of the variation in treatment days needed (Table 8). On average, reduction of 1 g/dl in TP only resulted in an extra half day of treatment for each condition.

4. Discussion

4.1. Analyses

Linear regression to determine if the level of total protein influenced the severity of disease (as measured by the duration of treatment) was done twice: First using all calves treated for a specific disease condition and second, using only those that survived the disease. We had postulated that two separate models would evolve. Calves that die, do so early in the course of the disease and thus, number of days treated would not be a good measure of severity in those calves. In fact, the parameter estimates in the two models were nearly identical and so, only the ones using all calves treated are presented.

The standard errors of the coefficients in the logistic regression models may have been underestimated because there was some evidence of 'clustering' of the data (intra-herd correlation coefficients between 0.004 and 0.16). However, for those conditions in which TP was associated with the dependent variable (i.e. mortality, septicemia and pneumonia), the level of statistical significance was very high ($P < 0.005$). Consequently, it is unlikely that clustering resulted in any spuriously-significant observations (McDermott and Schukken, 1994).

4.2. Mortality

The risk of calf mortality in this study was similar to those reported previously (Thomas and Swann, 1973; Hartman et al., 1974; Jenny et al., 1981; James et al., 1984) but higher than the estimated mortality rate in dairy calves reported in the National Animal Health Monitoring System (Gardner et al., 1990).

Calves with low TP values (< 5.0 g/dl) are 3 to 6 times more likely to die within the first six months of life than those with serum total protein concentrations of > 6.0 g/dl. This is in agreement with mortality risk ratios estimated from most of the relevant literature (McEwan et al., 1970; Boyd, 1972; McGuire et al., 1976; Fallon et al., 1987; Caldow et al., 1988; Robison et al., 1988).

The sample size of this study allows for detailed assessment of the shape of the association between serum total protein and mortality (Fig. 1). Evaluation of possible interactions among predictor variables is also a benefit of large sample size. In the mortality models, no significant interactions were found.

For a variety of reasons, TP was not determined in 121 calves. These calves were evenly distributed between barns. Thirty-seven (30.6%) of these calves died within 60 days of birth. A selection bias may have existed if these calves had a different distribution of TP values than calves included in the study. However, given the relatively small number of calves, any bias present was probably very small.

One unique finding of this study was the constant mortality hazard ratio throughout the period from birth through 6 months. It has always been felt that colostral protection was evident only early in life, and therefore, most research efforts were concentrated in the pre-weaning to 3-month time frame. Examination of data presented by Robison et al. (1988) reveals that calves with serum Ig concentration of less than 18 mg/ml when compared to those with Ig concentrations greater than 18 mg/ml had crude relative risks of mortality for the age ranges of 0–35 days, 36–70 days, 71–105 days and 106–180 days of 1.28, 3.44, 1.52 and 3.29, respectively. However, other calf and herd level factors that may have confounded these results were not noted in the paper.

Even with high apparent levels of absorbed colostral Ig, mortality risk was close to 10%. This emphasizes that other factors are involved with calf mortality besides level of humoral immunity. Colostrum does not completely overcome poor environmental or nutritional management.

4.3. Morbidity

4.3.1. Diarrhea

The lack of a significant association between TP and diarrhea could be expected. These farms practiced a sound *E. coli* vaccination program that included two doses of vaccine during the non-lactating period resulting in rare clinical or laboratory diagnosis of enteritis caused by *E. coli*. The primary enteric pathogens on these farms are rotavirus, coronavirus, cryptosporidia and *Salmonella* sp. Systemically-absorbed colostral Ig does not effectively prevent enteritis caused by these agents (Smith et al., 1980; Archambault et al., 1989; Harp et al., 1989).

4.3.2. Septicemia

Colostral protection of the calf from septicemia shown here agrees with other studies (McEwan et al., 1970; McGuire et al., 1976; Caldow et al., 1988). The relationship between TP and the occurrence of septicemia was linear. There was a seasonal interaction, increased risk in the summer, that can best be explained by the environment into which the calf is born. Coincident with the summer season in Florida is a significant increase in precipitation which presumably would lead to an increase in the pathogen load in the calving area and inside the calf housing area. The delay in onset of septicemia seen here was of little practical significance.

4.3.3. *Omphalitis*

Lack of demonstrable efficacy of passive Ig transfer against navel infections runs counter to conventional wisdom. Remarkably, very few scientific studies have been able to quantify any protection afforded by passive transfer or dipping of the navel in a disinfectant solution (Naylor et al., 1977; Waltner-Toews et al., 1986). Two factors could play a role in these negative findings. First, the health management practices on these farms are such that all navels were evaluated at 2 to 4 days of age and if the navel was swollen or had an abnormal discharge, antibiotic therapy was initiated. The possibility for non-differential misclassification of navel infections may be quite high, thus, reducing the chances of finding an association if there was one. The second possibility is that there is truly no association between colostral immunoglobulins and the occurrence of navel infections.

4.3.4. *Pneumonia*

Results shown here generally agree with other studies (Thomas and Swann, 1973; Davidson et al., 1981; Fallon et al., 1987; Howard et al., 1989; Belknap et al., 1991). However, as in the mortality model, the association between TP and the occurrence of pneumonia was a quadratic relationship that was independent of season and farm. The lack of seasonal interaction would be expected because of the delay in the onset of pneumonia to after 30 days of age; some calves born in one season would be at risk of getting diseased in another. The hazard of developing pneumonia was not constant over time; protection was strong in the young calf but had waned completely by 180 days of age. This makes biological sense in that it would be hard to expect colostral immunity to protect the calf after three of four months when factors such as overcrowding, parasitism and nutritional stress are likely much larger contributors to the occurrence of disease. However, in extensively-managed beef calves, Wittum and Perino (1995) found a strong association between FPT and feedlot morbidity due to pneumonia (OR = 3.0). The reasons for this discrepancy are not known.

5. Conclusions

Colostrally-derived immunoglobulins help protect the calf from mortality and morbidity due to septicemia and pneumonia. The preventive effect of colostrum with regards to mortality was quadratic in nature, implying that a much-greater improvement in calf mortality can be seen when TP is increased from 4.0 to 5.0 g/dl than there is when TP increases from 5.5 to 6.5 g/dl. These effects on mortality last longer than previously thought as evident by a constant mortality hazard ratio up to 6 months of age.

The positive relationship between TP and pneumonia also showed a decreasing curvilinear association (quadratic) whereas that for septicemia was linear. Once calves became ill with one of these diseases, serum total protein concentration had a significant-but biologically-minimal-effect on the number of treatment days needed. Passive transfer of immunoglobulins did not show any relationship to neonatal diarrhea or omphalitis.

Acknowledgements

The contributions of the management and staff of McArthur Farms and North Florida Holsteins are gratefully acknowledged.

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