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Partitioning the Mortality Risk Associated with Inadequate Passive Transfer of Colostral Immunoglobulins in Dairy Calves

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This study developed a method to partition the risk of mortality in dairy calves in the 1st 16 weeks of life. Observed population mortality and the relative risk of mortality in each serum protein concentration stratum were used to determine the population baseline mortality rate and the mortality rate due to inadequate passive transfer of colostral immunoglobulin. A total of 3,479 calves were studied, 8.2% of which died before 16 weeks of age. The population baseline mortality rate was 5.0% and the mortality rate due to inadequate passive transfer was 3.2%. Thirty-nine percent of the observed mortality was attributed to inadequate passive transfer. This partitioning of risk between passive transfer–related and unrelated sources should prove useful in conducting investigations of calf mortality problems in dairy herds.

Key words: Attributable risk; Colostrum; Epidemiology; Modeling.

Passive transfer of colostral immunoglobulin (IgG) (passive transfer) is a critical determinant of calf health and survival.[1–4] Total serum protein concentration serves as an excellent proxy for passive transfer status. Serum protein concentration is closely associated with serum IgG concentration in neonatal calves ($r^2 = 0.76$).[5] Consequently, serum protein concentration may be used to predict the relative risk of mortality in calves. One recently completed study presented relative risks for mortality in dairy replacement heifers with varying serum protein concentrations.[4] In this study, the relative risk of mortality in the 1st 16 weeks of life decreased with increasing serum protein concentrations until serum protein concentrations exceeded 5.5 g/dL. Thereafter, further increases in serum protein concentration were not associated with additional decreases in the risk of mortality. Additionally, this study determined that the effect of passive transfer status on calf mortality was independent from the baseline mortality risk. These observations suggest that the relative risk for mortality associated with varying serum protein concentrations can be extrapolated to farm environments with different baseline mortality risks.

Herd investigations of neonatal calf mortality typically explore a wide range of issues and concerns. Typically, these issues include passive transfer, hygiene, housing, and nutrition.[6–8] Data management tools that would partition the risk of mortality and attribute proportions of mortality to specific causes would permit practitioners to focus intervention efforts in areas with the greatest return on invested labor and resources. For example, if only 10% of a herd's calf mortality was attributable to inadequate passive transfer, a farm's intervention efforts logically would focus on hygiene, housing, and nutrition. Under these circumstances, efforts to improve calf passive transfer status would have minimal impact on calf mortality.

The purpose of this study was to develop intuitively logical models partitioning and attributing the risk of mortality in dairy calves. This partitioning of mortality risk would permit practitioners to focus herd intervention efforts on areas with the greatest likelihood of reducing calf mortality, and hence, maximizing farm productivity.

Materials and Methods

Study subjects included 3,479 calves raised on a contract calf-rearing farm in central Washington State between September 1986 and November 1995. Calves were received weekly from approximately 25 dairy farms in western Washington. Blood samples were collected from each calf within 3 days of arrival. Serum was harvested and serum protein concentration determined by refractometry. Entry and death dates were recorded and survival to 16 weeks of age was determined for each enrolled calf. The study site and sample collection procedure has been described more fully in a previous study.[4]

Calves were categorized based on their serum protein concentration. Class limits for these categories were < 4.0, 4.0–4.4, 4.5–4.9, 5.0–5.4, 5.5–5.9, and ≥ 6.0 g/dL. For each category the frequency of occurrence, the mortality rate, and the relative risk of mortality were determined using standard methods.[9] Additionally, the population mortality rate was calculated.

Development of the model was based on 2 assumptions. The 1st assumption was that no significant association existed between the interaction of serum protein concentration and baseline mortality with mortality. This assumption implies that the increased relative risk of mortality in calves with low serum protein concentrations remains constant at varying levels of baseline population mortality risk. The 2nd assumption was that serum protein concentrations exceeding 5.5 g/dL were not associated with any further reductions in mortality. Both assumptions were substantiated by a previous investigation completed with this study population.[4] Consequently, the number of mortalities in any serum protein concentration stratum was anticipated to be the baseline mortality experienced by calves with a serum protein concentration > 5.5 g/dL, multiplied by the relative risk of mortality for calves in that specific strata, multiplied by the relative frequency of the calves present in that serum protein concentration strata. The population mortality rate would then equal the sum of these strata-specific mortalities using the following formula[10]:

$$P_m = (F_{5.5}P_{5.5}) + (F_{5.0}RR_{5.0}P_{5.5}) + (F_{4.5}RR_{4.5}P_{5.5}) + (F_{4.0}RR_{4.0}P_{5.5}) + (F_{<4.0}RR_{<4.0}P_{5.5})$$

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Table 1. Proportionate mortality (P), relative risks for mortality (RR). and frequency of occurence (F) in a given serum protein concentration stratum (TP stratum) in a population of 3,479 dairy calves.

TP Stratum	n	Mortalities	P	RR	F
<4.0	60	14	0.233	4.64	0.017
4.0–4.4	366	57	0.156	3.10	0.105
4.5–4.9	775	86	0.111	2.21	0.223
5.0–5.4	904	60	0.066	1.32	0.260
≥5.5	1,374	69	0.050	1.00	0.395
Total	3,479	286	0.082		

where

P_m = observed population mortality rate,

$F_{5.5}$ = relative frequency of calves with serum protein concentrations ≥5.5 g/dL,

$P_{5.5}$ = the baseline population mortality rate in calves with serum protein concentration ≥5.5 g/dL,

$F_{5.0}$ = relative frequency of calves with serum protein concentrations ≥5.0 g/dL and <5.5 g/dL,

$RR_{5.0}$ = the relative risk of mortality in calves with serum protein concentrations ≥5.0 g/dL and <5.5 g/dL,

$F_{4.5}$ = relative frequency of calves with serum protein concentrations ≥4.5 g/dL and <5.0 g/dL,

$RR_{4.5}$ = the relative risk of mortality in calves with serum protein concentrations ≥4.5 g/dL and <5.0 g/dL,

$F_{4.0}$ = relative frequency of calves with serum protein concentrations ≥4.0 g/dL and <4.5 g/dL,

$RR_{4.0}$ = the relative risk of mortality in calves with serum protein concentrations ≥4.0 g/dL and <4.5 g/dL,

$F_{<4.0}$ = relative frequency of calves with serum protein concentrations <4.0 g/dL, and

$RR_{<4.0}$ = the relative risk of mortality in calves with serum protein concentrations <4.0 g/dL.

We then solved for $P_{5.5}$, the baseline mortality rate, using the calculated relative risks, the observed population mortality rate, and the relative frequency of calves in each serum protein concentration strata with serum protein concentrations ≥ 5.5 g/dL. Calf mortality directly attributable to impaired passive transfer (P_{fpt}) and the proportion of calf mortality associated with passive transfer (P_{fpt}) (attributable fraction [AF]) were then calculated using the following formulae[10]:

$$P_{fpt} = P_m - P_{\geq 5.5}$$

$$AF = (P_{fpt}/P_m)$$

Results

The observed mortality rate was 0.082. The relative risk of mortality ranged from 1.00 in calves with serum protein concentrations ≥5.5 g/dL to 4.64 in calves with serum protein concentrations <4.0 g/dL (Table 1). The calculations of baseline mortality rate, the mortality attributable to failure of passive transfer and the proportion of mortality attributable to failed passive transfer are illustrated below.

$$P_m = (F_{5.5}P_{5.5}) + (F_{5.0}RR_{5.0}P_{5.5}) + (F_{4.5}RR_{4.5}P_{5.5}) + (F_{4.0}RR_{4.0}P_{5.5}) + (F_{<4.0}RR_{<4.0}P_{5.5})$$

$$0.082 = (0.395 \times P_{5.5}) + (0.260 \times 1.32 \times P_{5.5}) + (0.223 \times 2.21 \times P_{5.5}) + (0.105 \times 3.10 \times P_{5.5}) + (0.017 \times 4.64 \times P_{5.5})$$

$$0.082 = (0.395 \times P_{5.5}) + (0.342 \times P_{5.5}) + (0.493 \times P_{5.5}) + (0.323 \times P_{5.5}) + (0.0789 \times P_{5.5})$$

$$0.082 = 1.632 \times P_{5.5}$$

$$P_{5.5} = 0.050$$

$$P_{fpt} = 0.082 - 0.050$$

$$P_{fpt} = 0.032$$

$$AF = P_{fpt}/P_m$$

$$AF = 0.032/0.082$$

$$AF = 0.39.$$

Discussion

The potential application of this model is straightforward. Morbidity and mortality in neonatal calves have complex etiologies that are best viewed as multifactoral. Factors often linked to outbreaks of disease in dairy calves are associated with less than optimal passive transfer status, exposure to a potentially virulent pathogen, inadequate sanitation and hygiene, and less than optimal nutritional support.[6–8] Investigation of acute calf mortality outbreaks and the development of health maintenance programs for calves will typically attempt to address all available predisposing or causal factors. Partitioning the calf mortality risk and isolating that component of mortality risk associated with failure of passive transfer will permit practitioners to expedite and focus intervention efforts and provide farmers with reasonable estimates of anticipated responses to intervention.

In the study population the observed mortality rate was 0.082. We calculated that 39% of calf mortality was due to inadequate passive transfer. Consequently, an intervention program that completely eliminated failed passive transfer would prevent only 39% of the observed moralities. The baseline mortality rate of 0.050 would remain unchanged, even if every calf had a serum protein concentration ≥ 5.5 g/dL. Such a dramatic change in the efficiency of passive transfer is unlikely. Less than 40% of the study population had serum protein concentrations ≥ 5.5 g/dL. In this population substantial decreases in mortality, such as a 50% reduction, would require simultaneous reductions in both baseline mortality and mortality attributable to failed passive transfer. Extrapolating from these observations, farms with low P_{fpt} can anticipate minimal improvement in calf mortality after improving herd passive transfer status. Farms with high P_{fpt} can expect more dramatic and substantial reductions in mortality. By calculating and partitioning these risks, we can better inform clients of anticipated responses to intervention and permit them to focus their efforts in those areas with the greatest potential for positive responses.

The limitations of this model are straightforward. To develop estimates of mortality associated with inadequate passive transfer, practitioners will need accurate mortality records that permit calculation of P_m and a sufficiently large calf population to permit calculation of the relative frequency of calves in each serum protein concentration stratum. Serum protein concentration is most accurate in the prediction of passive transfer status in very young calves. If a practitioner chose to sample only calves less than 2 weeks of age and wished to collect data from 20 calves, this calculation could only be applied to herds with more than 520 calves born each year (10 calves/week $\times$ 52 weeks/year). Many dairy farms are not large enough to support this type of data collection and risk calculation. Smaller farms can use these risk assessment strategies if monitoring for passive transfer status is routinely conducted as a component of a herd health program. Under these circumstances, historical data collection and mortality rates can be used to calculate the proportion of calf mortality attributable to inadequate passive transfer.

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