Effects of various vaccination protocols on passive and active immunity to Pasteurella haemolytica and Haemophilus somnus in beef calves

Joyce Van Donkersgoed, Cheryl Guenther, Brock N. Evans, Andy A. Potter, Richard J. Harland

Abstract
Two field trials were conducted in a beef cow herd in Saskatchewan to determine the effectiveness of a combined Pasteurella haemolytica and Haemophilus somnus vaccine in increasing passively and actively acquired antibodies in beef calves. Vaccination of dams at 4 and/or 7 weeks prepartum was associated with increased antibody titers to P. haemolytica and H. somnus in their serum (P < 0.05), colostrum (P < 0.05), and serum of their calves at 3 days and 1 month of age (P < 0.05). There was no significant (P > 0.05) difference in antibody titers in the colostrum and serum of calves from single or double vaccinated dams. Calves vaccinated at 1 and 2 months of age in the face of maternal antibodies to P. haemolytica and H. somnus had significantly (P < 0.05) higher antibodies to P. haemolytica and H. somnus at 4 and 6 months of age than did unvaccinated calves. Calves vaccinated at 3 and 4 months of age in the face of low levels of preexisting antibodies had significantly (P < 0.05) higher antibodies to P. haemolytica at 5 months of age and to H. somnus at 5 and 6 months of age than did unvaccinated calves. Calves vaccinated once at 4 months of age had significantly (P < 0.05) higher antibody titers to P. haemolytica and H. somnus at 4.5 months of age than did unvaccinated calves, but this difference was not apparent at 6 months of age. These results suggest that vaccination of beef cows with a combined Pasteurella haemolytica and Haemophilus somnus vaccine once at 4 weeks prepartum will significantly (P < 0.05) increase passive antibody titers to P. haemolytica and H. somnus in their calves. Double vaccination of calves with preexisting maternal antibodies at 1 and 2 months of age will increase antibody titers to P. haemolytica and H. somnus until 6 months of age. Vaccination of beef calves with low levels of preexisting antibody at 3 and 4 months of age will increase antibody titers to H. somnus until 6 months of age and to P. haemolytica until 5 months of age. However, the level of antibodies achieved by vaccination may depend on the calves being studied, the level of preexisting antibodies, and the efficiency of passive transfer.

Résumé
Évaluation de divers protocoles de vaccination et de l'efficacité sur l'immunité active et passive contre Pasteurella haemolytica et Haemophilus somnus chez les veaux
Deux études ont été effectuées sur le terrain chez des vaches de boucherie dans la province de la Saskatchewan afin d'évaluer l'efficacité d'un vaccin combiné contre Pasteurella haemolytica et Haemophilus somnus à stimuler la formation des anticorps passifs ou actifs chez les veaux. L'immunisation des vaches à quatre et/ou à sept semaines prepartum a produit une augmentation du taux d'anticorps contre P. haemolytica et H. somnus dans le sérum (P < 0.05) et le colostrum (P < 0.05) des vaches et dans le sérum de leurs veaux âgés de trois et de 30 jours (P < 0.05). Il n'y avait pas de différence significative (P < 0.05) dans le taux d'anticorps du colostrum ou du sérum des veaux dont la mère avait reçu une ou deux doses de vaccin. Les veaux vaccinés à l'âge d'un ou de deux mois et soumis à la présence d'anticorps maternels contre P. haemolytica et H. somnus ont montré un plus haut taux d'anticorps (P < 0.05) à l'âge de quatre et de six mois comparativement aux veaux non vaccinés. Les veaux vaccinés à l'âge de trois et de quatre mois et soumis à un faible taux d'anticorps maternels ont montré un plus haut taux d'anticorps (P < 0.05) contre P. haemolytica à l'âge de cinq mois et contre H. somnus à l'âge de cinq et de six mois comparativement aux veaux non vaccinés. Les veaux vaccinés une fois à l'âge de quatre mois ont eu des taux d'anticorps plus élevés (P < 0.05) contre P. haemolytica et H. somnus à l'âge de quatre mois et demi comparativement aux veaux non vaccinés. Toutefois, cette différence ne fut pas apparente à l'âge de six mois.

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Les résultats suggèrent que l'utilisation du vaccin combiné contre *P. haemolytica* et *H. somnus* administré quatre semaines prepartum chez les vaches de boucherie fera augmenter de façon significative (*P < 0.05*) les taux d'anticorps passifs chez leurs veaux. L'immunisation des veaux soumis aux anticorps maternels à l'âge d'un et de deux mois augmentera leur taux d'anticorps jusqu'à l'âge de six mois. L'immunisation des veaux ayant un faible taux d'anticorps maternels à l'âge de trois et de quatre mois augmentera les taux d'anticorps contre *H. somnus* jusqu'à l'âge de six mois et ceux de *P. haemolytica* jusqu'à l'âge de cinq mois. Toutefois, le taux d'anticorps obtenu par la vaccination pourra varier selon l'animal étudié, le taux d'anticorps maternels et l'efficacité du transfert passif.

(Traduit par Docteure Thérèse Lanthier)


Introduction

Enzootic pneumonia occurs frequently in beef and dairy calves in western Canada, with morbidity risks of 0% to 91%, recurrence risks of 29% to 56%, and mortality risks of 0% to 7% (1,2). Disease is observed most frequently within the first few months of life, yet calves at all ages are at risk (1,2). The occurrence of pneumonia depends on a series of complex interactions among several different infectious agents, the immunological status of the calf, and environmental factors (1–3). A variety of infectious agents have been isolated from pneumonic lungs of calves, including *Pasteurella haemolytica* and *Haemophilus somnus* (2,4).

Prevention and control of pneumonia is best achieved by maximizing the calf’s immunity to the common infectious agents of pneumonia (5–12). Studies have shown that high levels of antibodies prior to infection may reduce the risk of disease (2,13). Passively acquired antibodies to *P. haemolytica* have been shown to reduce the risk of enzootic pneumonia in dairy calves (2). High levels of actively acquired antibodies to the leukotoxin of *P. haemolytica* have been shown to reduce the risk of pasteurellosis in beef calves, infected experimentally or naturally (5). The role of antibodies in immunity to *H. somnus* infection is unclear; however, it has been reported that in feedlot calves, antibodies to the outer membrane proteins of *H. somnus* are associated with the risk of 2nd relapses to pneumonia and mortality from pneumonia and hemophilosis (7).

A recent study has suggested that vaccination of dairy cows with a *P. haemolytica* bacterial toxoid extract at 3 and 6 wk prepartum may cause increases in the levels of passive antibodies to *P. haemolytica* in their calves (4). There are no reports evaluating the effectiveness of single versus double vaccination prepartum in beef cows to increase passive antibody titers to *P. haemolytica* and *H. somnus* in their calves. Similarly, there are few reports that demonstrate the ability of *P. haemolytica* and *H. somnus* vaccines to stimulate the development of antibodies when used in young beef calves with preexisting maternal antibodies that, theoretically, could interfere with the calf’s immune response to vaccination (1).

The purpose of the field trials reported was to evaluate the effectiveness of a vaccine with genetically attenuated leukotoxin of *P. haemolytica* and bacterial extracts of *P. haemolytica* and *H. somnus* (Somnu-Star Ph, Biostar Inc., Saskatoon, Saskatchewan) in increasing antibody titers to *P. haemolytica* and *H. somnus* in calves when given to beef cows 4 and/or 7 wk prepartum and when given to calves at 1 and 2 mo or 3 and/or 4 mo of age.

Materials and methods

**Trial 1**

This field trial was conducted in a crossbred beef herd of 119 cows. Cows ranged in age from 3 to 9 y and were expected to begin calving in March. Formerly, vaccination against *P. haemolytica* and *H. somnus* was not used in the cows from this herd or in their calves until after weaning (>6 mo of age). Approximately 7 wk before the beginning of the calving season (*x = −50 d, s = 10 d*), all cows were randomly assigned to 1 of 3 vaccine groups: 1) no vaccine, 2) vaccine at 7 and 4 wk prepartum (*x = −29 d, s = 10 d*), or 3) vaccine at 4 wk prepartum. Cows were immunized with 2 mL of vaccine, IM, in the neck. Blood samples were collected from cows at each vaccination and within 12 h after calving for serological assays to *P. haemolytica* and *H. somnus*.

Cows were mingled in corrals prior to calving. The calving season began February 25 and ended April 23. Calving records were maintained by an experienced animal health technician. Two cows were culled prior to calving and 3 cows did not have a live calf at birth. The technician made sure that all calves receivedcolostrum from their respective dams shortly after birth. Within 12 h of calving, colostrum samples were collected from each cow and stored frozen at −20°C, until they were assayed.

Blood samples were collected from newborn calves at an average of 3 d of age (range 2 to 4 d) to measure total protein and antibody titers to *P. haemolytica* and *H. somnus*.

At approximately 1 mo of age, 113 calves were systematically randomized at handling to 1 of 2 vaccine groups: 1) no vaccine or 2) vaccine at 1 mo (*x = 28 d, s = 5 d*) and 2 mo (*x = 56 d, s = 6 d*) of age. Calves were immunized with 2 mL of vaccine, SC, in the neck. Blood samples were collected from calves at each vaccination and at 4 mo (*x = 110 d, s = 10 d*) and 6 mo (*x = 172 d, s = 10 d*) of age for serological assays to *P. haemolytica* and *H. somnus*.

While collecting blood samples from calves on May 27, we observed that some calves were unthrifty. Three calves had died prior to this date and necropsy results in 1 calf indicated white muscle disease. Therefore, all calves were treated with injectable selenium (Dystosel, rogar/STB, Pfizer Canada Inc., Pointe Claire-Dorval, Quebec) at recommended levels.

Cows and calves were mingled in corrals until May and then moved to summer pasture until weaning. Personnel were blind to the vaccine status of animals.

Animals were used in accordance with the guidelines of the Canadian Council of Animal Care.

**Trial 2**

One hundred and thirty-two crossbred beef calves, born in March and April, were used in this field trial. At approximately 3 mo of age, all calves from the herd were randomized to 1 of 3 vaccine groups: 1) no vaccine;
2) vaccine given at 3 and 4 mo of age; or 3) vaccine given at 4 mo of age. Calves were injected, IM, with 2 mL of vaccine. Calves in vaccine group 2 received the vaccine on June 21 and again on July 12, whereas the calves in vaccine group 3 received the vaccine only once, on July 12. Vaccination was timed in this manner so that 1- and 2-dose vaccine regimes could be compared in calves of similar age.

Blood samples were collected from calves on June 21, July 12, July 28, August 26, and September 27 for serological assays to *P. haemolytica* and *H. somnus*. During the study, calves were mingled with their dams on summer pasture. Personnel were blind to the vaccine status of animals. Two calves were lost to follow-up due to errors in reading eartags.

**Serological and statistical methods**

Colostral whey was separated from butterfat and casein using rennin tablets obtained at a health food store. Tablets were dissolved in water and a few drops of the rennin suspension were added to each 20 mL sample of colostrum and then incubated for 1 h at 37°C. Samples were centrifuged at 1500 g for 30 min and the whey was removed.

Sera and colostral whey samples were tested for antibodies to the leukotoxin of *P. haemolytica* and outer membrane proteins of *H. somnus* using an enzyme-linked immunosorbent assay (ELISA), as described previously (8). Total protein in the serum of calves at 3 d of age was measured by a refractometer to give an indication of the efficiency of passive transfer (14).

Data were entered into databases in the Statistical Analysis System (SAS/STAT 1989, Version 6, SAS Institute Inc., Cary, North Carolina, USA). Antibody titers (ELISA) were coded as the log g.titer, reciprocal of the endpoint. Differences in titers among vaccine groups were assessed using the general linear model (GLM) with repeated measures over time and Tukey’s multiple comparison of means. Differences in titer change among vaccine groups were assessed using GLM and adjusting for initial titers. The χ²-test, analysis of variance test, and r-test were used to assess associations among vaccination, total protein, colostral titers, neonatal titers, calf death, and calf age at 1st sampling. Pearson correlation coefficients were used to measure the association among total protein, colostral titers, and serum titers.

**Results**

**Trial 1**

Prepartum vaccination of beef cows with the vaccine significantly (*P < 0.05*) increased antibody titers to *P. haemolytica* and *H. somnus* in the serum and colostrum of cows and the serum of their calves (Table 1). There was no significant (*P > 0.05*) difference in antibody titers to *P. haemolytica* and *H. somnus* in the serum or colostrum of cows at calving or the serum of calves at 1 mo of age between those vaccinated once at 4 wk prepartum or those vaccinated at 4 and 7 wk prepartum (Table 1). Preexisting antibody titers in cows were negatively (*P < 0.05*) associated with titer change following primary vaccination (data not shown). Serum antibody titers to *P. haemolytica* (*r = 0.79*) and *H. somnus* (*r = 0.62*) in cows at calving were positively (*P < 0.05*) associated with colostral antibody levels. Similarly, colostral antibody titers to *P. haemolytica* (*r = 0.45*) and to *H. somnus* (*r = 0.29*) were positively

<table>
<thead>
<tr>
<th>GMT ELISA</th>
<th>Cow vaccination</th>
<th>Titer change</th>
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<tbody>
<tr>
<td></td>
<td>Control</td>
<td>4 wk</td>
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<tr>
<td>Number of cows</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total protein (g/L)</td>
<td>64⁺</td>
<td>64⁺</td>
</tr>
<tr>
<td>Leukotoxin⁺⁺</td>
<td>Cow’s serum:</td>
<td>7 wk</td>
</tr>
<tr>
<td></td>
<td>4 wk</td>
<td>43 647⁺</td>
</tr>
<tr>
<td></td>
<td>0 wk</td>
<td>45 640⁺</td>
</tr>
<tr>
<td>Colostrum⁺⁺</td>
<td>7450⁺</td>
<td>84 907⁺</td>
</tr>
<tr>
<td></td>
<td>28 d</td>
<td>1511⁺</td>
</tr>
<tr>
<td></td>
<td>28 d</td>
<td>438⁺</td>
</tr>
<tr>
<td>Haemophilus somnus⁺⁺</td>
<td>Cow’s serum:</td>
<td>7 wk</td>
</tr>
<tr>
<td></td>
<td>4 wk</td>
<td>5421⁺</td>
</tr>
<tr>
<td></td>
<td>0 wk</td>
<td>4490⁺</td>
</tr>
<tr>
<td>Colostrum⁺⁺</td>
<td>2637⁺</td>
<td>16 468⁺</td>
</tr>
<tr>
<td></td>
<td>28 d</td>
<td>622⁺</td>
</tr>
<tr>
<td></td>
<td>28 d</td>
<td>97⁺</td>
</tr>
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</table>

**Table 1. Antibody titers to Pasteurella haemolytica and Haemophilus somnus in serum and colostrum of dams and calves after preparturient vaccination (Trial 1)**

**Notes:**

- GMT = geometric mean titer
- ELISA = enzyme-linked immunosorbent assay
- ⁺⁺ denotes value of titer change differences (current titer − previous titer) among vaccine groups
- Total protein measured in the serum of 2- to 4-day-old calves
- Antibodies to leukotoxin of *Pasteurella haemolytica*
- Antibody titers at calving, samples collected within 12 h postcalving
- Antibodies to outer membrane proteins of *Haemophilus somnus*
- Significant difference (*P < 0.05*) among cow vaccine groups within row
(P < 0.05) associated with serum antibody titers in calves at 3 d of age.

One percent of the calves had total protein levels <50 g/L, indicating failure of passive transfer (14). Thirty-two percent of the calves had total protein levels from 50 to 60 g/L, and 67% had levels >60 g/L. Total protein levels were associated (P < 0.05) with calf age at collection. Calves that were 2 d of age had higher total protein levels on average than those that were 3 or 4 d of age (66 g/L vs 63 g/L and 59 g/L). Total protein levels were not associated (P > 0.05) with Colostral or Neonatal antibody titers, Vaccination, or Cow age. Cow age was not associated (P > 0.05) with Colostral or Neonatal antibody titers or Vaccination, but it was associated (P < 0.05) with Serum antibody titers to P. haemolytica and H. somnus at 7 wk prepartum (lowest level in 3-year-old cows). Calf age at 1st sampling was not associated (P > 0.05) with Vaccination or Colostral and Neonatal antibody titers.

Six calves died between birth and weaning from stillbirth, meningitis, cardiac anomaly, white muscle disease (n = 2), or unknown causes. Calf death was not associated (P > 0.05) with total protein, Colostral antibody titers, neonatal antibody titers, or Vaccination.

Calves vaccinated at 1 and 2 mo of age had higher (P < 0.05) antibody titers to P. haemolytica and H. somnus at 6 mo of age than those that were unvaccinated (Tables 2 and 3). Preexisting antibody titers significantly (P < 0.05) reduced titer change following primary vaccination (data not shown). A few calves developed subcutaneous swellings following vaccination, but they resolved spontaneously over time.

The various cow and calf vaccination strategies are shown in Table 3. Vaccination of the dam prepartum increased (P < 0.05) serum titers to P. haemolytica and H. somnus in calves up to 2 mo of age in contrast to calves from nonvaccinated dams. Calves vaccinated at 1 and 2 mo of age, regardless of cow vaccination, had significantly (P < 0.05) higher antibody titers to P. haemolytica and H. somnus at 6 mo of age than did those that were not vaccinated.

**Table 2. Antibody titers to Pasteurella haemolytica and Haemophilus somnus in serum of beef calves vaccinated at 1 and 2 months of age (Trial 1)**

<table>
<thead>
<tr>
<th>GMT</th>
<th>ELISA</th>
<th>Vaccination</th>
<th>Titer change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>None</td>
<td>1 + 2 mo</td>
</tr>
<tr>
<td>Number of calves</td>
<td>57</td>
<td>56</td>
<td>14</td>
</tr>
<tr>
<td>Total protein (g/L)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>63&lt;sup&gt;e&lt;/sup&gt;</td>
<td>63&lt;sup&gt;e&lt;/sup&gt;</td>
<td>14</td>
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<td>Leukotoxin&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7986&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11 025&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11</td>
</tr>
<tr>
<td>3 d</td>
<td>5986&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3839&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31</td>
</tr>
<tr>
<td>1 mo</td>
<td>1127&lt;sup&gt;a&lt;/sup&gt;</td>
<td>980&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30</td>
</tr>
<tr>
<td>2 mo</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>909&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0001</td>
</tr>
<tr>
<td>4 mo</td>
<td>18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>499&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33</td>
</tr>
<tr>
<td>6 mo</td>
<td>2461&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4460&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14</td>
</tr>
<tr>
<td>Haemophilus somnus&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1528&lt;sup&gt;a&lt;/sup&gt;</td>
<td>625&lt;sup&gt;a&lt;/sup&gt;</td>
<td>03</td>
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<tr>
<td>3 d</td>
<td>177&lt;sup&gt;a&lt;/sup&gt;</td>
<td>233&lt;sup&gt;a&lt;/sup&gt;</td>
<td>07</td>
</tr>
<tr>
<td>1 mo</td>
<td>7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>326&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0001</td>
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<tr>
<td>2 mo</td>
<td>44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3754&lt;sup&gt;a&lt;/sup&gt;</td>
<td>01</td>
</tr>
</tbody>
</table>

GMT = geometric mean titer
ELISA = enzyme-linked immunosorbent assay
<sup>a</sup>P value for titer change (current titer − previous titer) between vaccine groups
<sup>b</sup>Total protein (g/L) in serum of 2- to 4-day-old calves
<sup>c</sup>Antibody titers to leukotoxin of Pasteurella haemolytica
<sup>d</sup>Antibody titers to outer membrane proteins of Haemophilus somnus
<sup>e</sup>Significant difference (P < 0.05) between vaccine groups within row

Discussion

Prepartum vaccination of beef cows resulted in significant (P < 0.05) increases in antibody titers to P. haemolytica and H. somnus in their calves, which persisted until 2 mo of age. Colostral antibody titers were positively (P < 0.05) associated with serum antibody titers in the cow at calving and in the neonatal calf. This finding was similar to a study performed in dairy cows, where prepartum vaccination with a P. haemolytica vaccine (Presponsor, Langford Inc., Guelph, Ontario) at 3 and 6 wk prepartum caused increases in neonatal antibody titers to P. haemolytica (4). However, in that study the outcome was affected by the particular dairy herd studied and the antigen measured. In 3 of the 5 dairy herds, the mean serum IgG1 levels in calves suggested failure or partial failure of passive transfer of immunoglobulins, which could affect the benefits of vaccination. In our beef herd, 33% of the calves had failure or partial failure of passive transfer, similar to previous reports (2,4). Total protein levels were not associated (P > 0.05) with Neonatal antibody titers or Vaccination, and thus did not obscure the effect of vaccination on passive antibody titers. However, the magnitude of the difference in Neonatal antibody titers between calves that were vaccinated and those that were not vaccinated might have been larger if all calves had adequate passive transfer. Therefore, it is important to remember that the effectiveness of prepartum vaccination of the dam depends on the efficiency of passive transfer of immunoglobulins to the calf.

There was no added benefit to vaccinating cows twice prepartum in contrast to once prepartum. Cows had preexisting antibodies to P. haemolytica and H. somnus; therefore, a single vaccination was effective in boosting preexisting antibody levels. Antibodies to P. haemolytica and H. somnus are commonly found in beef and dairy calves (1,2,4,7,13), suggesting that these agents are prevalent in the cattle population. As with scour vaccines, however, it may be a wise management practice to vaccinate 1st-calf heifers twice prepartum, because they generally have lower antibody titers to infectious agents than do older cows, like the 3-year-old cows in our study. Single prepartum vaccination increased antibody titers in cows with preexisting antibodies; however, higher
antibodies in the serum, prevaccination, were associated with lower responses to vaccination.

The increase in antibody titers to *P. haemolytica* and *H. somnus* in the serum of calves from vaccinated dams persisted until 2 mo of age, suggesting that prepartum vaccination may be a useful management tool in herds where calf pneumonia from *P. haemolytica* and *H. somnus* occurs within the first 2 mo of life. Passively acquired antibodies to *P. haemolytica* have been shown to reduce the risk of enzootic pneumonia in dairy calves (2).
However, the protective effect of passive antibodies to *H. somnus* has not yet been determined.

Vaccination of beef calves at 1 and 2 mo of age in the face of preexisting antibodies resulted in higher antibody titers to *P. haemolytica* and *H. somnus* until 6 mo of age compared with titers in calves not vaccinated. Most likely these preexisting antibodies were maternally derived, since there was no serological or clinical evidence of natural infection with *P. haemolytica* and *H. somnus* during the study. Preexisting antibodies appeared to interfere with the antibody response to primary vaccination; however, upon revaccination, calves showed an increase in antibodies to *H. somnus* and a slower decline to antibodies to *P. haemolytica* than did those not vaccinated. This finding suggests that primary vaccination primed some immune cells, which responded to 2nd vaccination despite the presence of preexisting maternal antibodies. Our findings support those of a previous field study, which evaluated the effect of the same vaccine in beef calves vaccinated at 3 and 5 wk of age (1). The antibody titers to *P. haemolytica* and *H. somnus* appeared higher in response to the vaccine in the previous study (1), in contrast to the titers reported here. These antibody values may differ between the 2 trials, because 1) a different negative control and a different method of calculation of ELISA titers were used, 2) the calf population under study was different (4), and 3) the calves were suffering from selenium and/or vitamin E deficiency. In the trial reported here, calves had signs of selenium/vitamin E deficiency based on death from white muscle disease and unthriftness. Selenium and vitamin E levels have been reported to affect the humoral immune response to *P. haemolytica* vaccines (15).

Calves vaccinated at 3 and 4 mo of age had higher antibody titers to *P. haemolytica* and *H. somnus* at 5 and 6 mo of age, respectively, in contrast to those that were not vaccinated. The antibody response to vaccination appeared stronger in these calves than in those vaccinated at 1 and 2 mo of age. This may have been due to the absence of high levels of preexisting antibody, which interfered with subsequent titer changes following primary vaccination, or to other differences between the 2 populations under study (4). Our data suggest that more serological studies are needed before the results can be generalized to all beef cattle herds. Additionally, larger-sized field studies in high-risk beef herds are needed to show that these antibodies are protective against naturally occurring disease.

**Acknowledgments**

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**References**


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