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Immune Response to Bovine Respiratory Disease Vaccine Immunogens in Calves at Entry to Feedlot and Impact on Feedlot Performance

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Abstract

Predictors of feedlot performance including clinical illness (morbidity), treatments, cost of treatments, and economic return of calves in a retained ownership program were measured using testing of samples collected at entry from post-weaning calves. At the delivery point, cattle were processed and samples were collected for laboratory testing, including nasal swabs for viral and bacterial isolation, EDTA blood for viral isolation from peripheral blood leukocytes, and serums for antibody testing against bovine herpesvirus-1 (BHV-1), bovine viral diarrhea virus (BVDV) 1a and BVDV2a, parainfluenza-3 virus (PI-3V), bovine respiratory syncytial virus (BRSV), *Mannheimia haemolytica* whole cell (WC) antigen, *M. haemolytica* leukotoxin (LKT), and *Pasteurella multocida* outer membrane proteins (OMP). Feedlot performance records and carcass data obtained at the close of the feeding period revealed predictors of feedlot performance and economic return based on lower or higher levels of serum antibodies to several BRD pathogens. These were based on both individual animal comparisons and herd averages. On an individual animal basis, low antibodies to BVDV1a, BVDV2a, *M. haemolytica* WC, *M. haemoytica* LKT, *P. multocida* OMP, BHV-1, PI-3V, and BRSV were associated with one or more of the following: increased morbidity, increased number of treatments, increased treatment costs, and decreased net value to owner (carcass value minus total costs in the feedlot). On a herd basis, low antibodies to BVDV1a, BHV-1, *P. multocida* OMP, *M. haemolytica* WC, and *M. haemolytica* LKT were associated with one or more of the following: increased morbidity, increased number of treatments, increased treatment costs, and decreased net value to owner. These results reaffirm that post-weaning calves with increased immunity to (antibody levels) BVDV, BHV-1, PI-3V, BRSV, *M. haemolytica*, and *P. multocida* perform better in the feedlot with less effects clinically to these BRD pathogens and provide greater economic return to the owner. Management for the breeding cow-herd owner retaining calves for feedlot delivery should stress vaccination against these pathogens.

Keywords: bovine respiratory disease, immunity, vaccines

Résumé

Des facteurs prédictifs de la performance en parc d'engraissement, incluant la prévalence de maladie clinique (morbidité), la fréquence des traitements, le coût des traitements et les retours économiques des veaux d'embouche, ont été mesurés avec des échantillons recueillis au moment de l'entrée des veaux sevrés. À l'abattage, des échantillons ont été prélevés pour des

analyses en laboratoire incluant des écouvillons nasaux pour l'isolement bactérien et viral, du sang avec l'anticoagulant EDTA pour l'isolement viral à partir des leucocytes du sang périphérique, et du sérum pour tester la présence d'anticorps contre l'herpèsvirus bovin de type 1 (BHV-1), le virus bovin de la diarrhée virale (BVDV1a et BVDV 2a), le virus parainfluenza de type 3 (PI-3V), le virus respiratoire syncytial bovin (BRSV), l'antigène de cellule entière de *Mannheimia haemolytica* (WC), la leucotoxine de *M. haemolytica* (LKT), et les protéines de la membrane externe de *Pasteurella multocida* (OMP). Les données de performance en parc d'engraissement de même que celles sur les carcasses à l'abattage ont permis d'identifier des facteurs prédictifs de la performance en engraissement et des retours économiques subséquents basés sur la diminution ou l'augmentation de la concentration des anticorps sériques contre plusieurs pathogènes respiratoires bovins. Ces facteurs prédictifs étaient basés soit sur des comparaisons individuelles ou soit sur des valeurs moyennes de troupeaux. Sur la base de valeurs individuelles, des valeurs moindres d'anticorps contre BVDV1a, BVDV2a, l'antigène de cellule entière de *M. haemolytica*, la leucotoxine de *M. haemolytica*, les protéines de la membrane extérieure de *P. multicoda*, BHV-1, PI-3V et BRSV étaient associées avec l'une ou plusieurs des conséquences suivantes : morbidité accrue, nombre accru de traitements, coûts plus élevés des traitements et diminution de la valeur nette pour le propriétaire (la valeur de la carcasse moins les coûts totaux dans le parc). Sur la base des valeurs au niveau du troupeau, des valeurs moindres d'anticorps contre BVDV1a, BHV-1, les protéines de la membrane extérieure de *P. multicoda*, l'antigène de cellule entière de *M. haemolytica* et la leucotoxine de *M. haemolytica* étaient associées avec l'une ou plusieurs des conséquences suivantes : morbidité accrue, nombre accru de traitements, coûts plus élevés des traitements et diminution de la valeur nette pour le propriétaire. Ces résultats reconfirment que les veaux sevrés ayant une meilleure réponse immunitaire (anticorps plus élevés) face aux agents suivants : BVDV, BHV-1, PI-3V, BRSV, *M. haemolytica* et *P. multicoda*, ont une performance supérieure en parc d'engraissement avec moins d'effets cliniques contre ces pathogènes respiratoires bovins et offrent un meilleur rendement économique pour le propriétaire. Au niveau de la régie, les propriétaires de bovins de reproduction, dans les troupeaux qui gardent leurs veaux pour le parc d'engraissement, devraient mettre l'accent sur la vaccination contre ces pathogènes respiratoires.

Introduction

Bovine respiratory diseases (BRD) have a significant economic impact on the beef cattle industry, ranging from breeding cow-herd owners, stocker operators purchasing weaned calves for development and gain on forage, and eventually feedlot operations. Economic losses to producers result from death (mortality), reduced feed conversion, reduced value of carcass at processing, and increased labor and treatment costs.[18,19,22,23,25]

Proactive attempts, including vaccinations, have been made to reduce the impact of losses due to BRD by management practices for various management types including cow-calf operations, stocker calf operations, dairy calves, and feedlots.[6,17,24,26,28] Studies have been conducted evaluating viral and bacterial vaccines for BRD control that are part of the feedlot entry processing protocol.[22,29] For cow-calf operations with calves destined for stocker operations or feedlots, preconditioning programs are designed to enhance health status of the cattle. As post-weaned calves leave the farm, they often enter marketing channels whereby they could be exposed to cattle from ranches or farms with an unknown or absent vaccination history for the infectious agents associated with BRD.[7,10,12,13,27] Ideally, calves should have immunity to these agents prior to commingling with other cattle.

Infectious viral agents associated with BRD include bovine herpesvirus-1 (BHV-1), multiple subtypes of bovine viral diarrhea virus (BVDV), parainfluenza-3 virus (PI-3V), bovine respiratory syncytial virus (BRSV), bovine adenoviruses, and bovine coronaviruses.[1,7,10,12,13,15,16,27] Currently in the US there are licensed and commercially available viral vaccines for BHV-1, BVDV, PI-3V, and BRSV.[2] The BRD bacterial pathogens include *Mannheimia haemolytica, Pasteurella multocida, Histophilus somni*, and *Mycoplasma* spp;[1,9,10-14] there are licensed and commercially available vaccines in the US for each of these pathogens.[2] Proper immunity to the above viral and bacterial pathogens is important because they have been identified by isolation and/or serology in commingled post-weaned calves purchased at auction markets and observed for 35 days.[7,10,12,13] This transmission also was observed when fresh ranch calves were mixed with these commingled auction market calves.

Preconditioning programs should be instituted at the earliest point of intervention, the breeding cow-herd. These programs generally prepare the weaned calf to meet the "stresses" occurring when: 1) the calf comes in contact with other cattle of unknown vaccination status that are potentially shedding numerous infectious agents; 2) the calf is placed in an environment facilitating transmission, such as trucking over long distances; 3) there is overcrowding in the markets and shipping; 4) the calf develops a compromised immune system; 5) the calf is exposed to environmental conditions such as dust, humidity, and environmental temperature changes; and 6) nutrition changes predispose the calf to increased BRD risk. Preconditioning programs often require

weaning of calves 30 to 45 days prior to shipment and commingling, and include dehorning, castration of bulls, anthelmintic treatment, vaccinations, and good nutritional status (some suggest or require calves to be bunk fed). Vaccination requirements are often prevalent in preconditioning programs, yet unfortunately documentation of efficacy of viral and bacterial vaccines under field conditions is limited.[20] We have reported previously in an initial study with cattle in a preconditioning program that calves with better or increased humoral immunity (antibody levels) to certain BRD pathogens had better feedlot performance than those with lower levels of immunity.[11]

Current cattle marketing often involves sale of recently weaned calves through auction markets or order buyers, wherein calves are purchased from many farms/ranches and/or auction markets, commingled, and shipped to stocker operations or feedlots. This sale of recently weaned calves through auctions is more common than "retained ownership programs" (ROP), whereby the breeding herd owner maintains ownership through the feeding period. These ROP are often associated both as an educational tool and as an economic benefit to the owner of calves. By retaining ownership, breeding cow-herd owners may potentially increase economic return if they have better genetic potential in their cattle to capture increased feedlot performance and carcass value at harvest processing. Also by retaining ownership, owners could benefit with healthier cattle with a return on their preconditioning costs.

The Noble Foundation (NF) Agricultural Division, Ardmore, Oklahoma (OK), provides educational programs to cooperating ranches in southern Oklahoma and northern Texas. Ranchers receive programs and consultation regarding nutrition for cattle, forage management, and breeding, including selection of heifers, cows, and bulls for a variety of traits. With educational programs above, attention is given to the economic impact of decisions. The NF ROP permits cooperators to select representative cattle for delivery to the NF ranch where they are processed, weighed, and shipped to a feedlot. The ROP ranchers learn how their cattle perform compared to industry norms, which allows them to see how their health programs prepare cattle for the feedlot as well as how the decisions on breeding females and bull selection impact feedlot performance. The NF ROP recommends that cattle be weaned 45 days prior to shipment, males be castrated, and all cattle be dehorned. Calves also are to receive anthelmintic treatment. The recommended vaccines include clostridial vaccines and two doses of viral vaccine. Use of *M. haemolytica* and *P. multocida* vaccines is highly recommended. Choice of vaccines, including modified-live virus (MLV) or killed viral (KV), is left to the rancher based on their management strategy and veterinarian's counsel.

The objective of this study was to determine predictors of health status in the feedlot, including treatment costs, morbidity, mortality, and other economic findings by collecting samples at processing for viral and bacterial serology, and detection of viruses and bacteria present in nasal swabs or blood samples.

Materials and Methods

Cattle and Sample Collection

There were 18 herds with 291 calves from southern Oklahoma and north-central Texas participating in the 2001-2002 NF ROP. Guidelines for the program including vaccinations, weaning, and anthelmintic treatment, plus dehorning and castration of males, had to be completed prior to delivery to the NF Coffey Ranch near Marietta, OK. The calves were delivered November 15-16, 2001 for processing, which included weighing, identification, and sample collection. Samples included nasal swabs for viral and bacterial isolation, an EDTA blood sample for BVDV isolation from peripheral blood leukocytes (PBL), and clotted blood samples for serum to be tested for viral and bacterial antibodies. Owners provided a herd health history, including weaning date, specific vaccines used, vaccination dates, anthelmintic used, and annual herd vaccinations. The vaccination histories for each herd (18) are summarized in Table 1. The calves were then shipped to a western Oklahoma feedlot near Guymon, a distance of approximately 380 miles (about 600 km). To assign a value to the calves at processing, the price for steers and heifers based on prices for that day at markets was used.

During processing at the feedlot, calves received a vaccine containing MLV BHV-1, BVDV1a, PI-3V, and BRSV. The normal pull-and-treat regimen for the feedlot was followed.[11] An animal was pulled from the pen for respiratory disease when one or more of the following signs were present: depression, nasal discharge, lack of rumen fill, and lethargy. If the rectal temperature was less than 104°F (40°C), the calf was called a "respiratory observe", given an MLV BHV-1 vaccine, and sent to a hospital observation pen. Calves that died during the study were necropsied, and tissues were collected for histopathologic study and viral/bacterial isolation. The diagnosis of enterotoxemia was based on clinical signs and necropsy. Numerous performance data were obtained from the cattle at delivery and during the feeding period. Carcass data was obtained at processing (Table 2).

Virologic, Bacteriologic, and Serologic Studies

Blood samples and nasal swabs were submitted to the Oklahoma Animal Disease Diagnostic Laboratory in Stillwater for viral and bacterial isolation.[10,11,12,13,21] A microtiter virus neutralization test was used to assay for

Table 1. Herd vaccination histories.

Herd no.	Delivery date	Vaccines	Dates of vaccinations
1	11/15	Killed BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV[a]	5/24
		MLV BHV-1, BVDV1a, PI-3V, and BRSV[b]	9/22 and 10/20
		Mannheimia haemolytica bacterin-toxoid[c]	9/22 and 10/20
2	11/15	MLV BHV-1, BVDV1a, PI-3V, and BRSV[b]	9/17 and 10/12
		Chemically altered ML BHV-1 and PI-3V[d] (intranasal)	9/17
		M. haemolytica bacterin-toxoid[c]	10/21
3	11/15	MLV BHV-1, BVDV1a, PI-3V, and BRSV[e]	9/15 and 10/01
		M. haemolytica toxoid[f]	9/15 and 10/01
4	11/15	Chemically altered ML BHV-1 and PI-3V, killed BVDV (one BVDV1a and one BVDV1 subtype not specified)[g]	9/3 and 10/4
5	11/15	MLV BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV[h]	9/25 and 11/8
6	11/15	MLV BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV	10/1
		ML *M. haemolytica* and *Pasteurella multocida*[i]	
		MLV BRSV[j]	10/22
7	11/15	Killed BHV-1, BVDV1a, PI-3V, and BRSV[k]	5/15 and 8/20
8	11/16	Chemically altered ML BHV-1 and PI-3V, killed BVDV (one BVDV1a and BVDV1 subtype not specified)[g]	9/12 and 10/30
		M. haemolytica bacterin-toxoid[c]	9/12
9	11/16	MLV BHV-1, BVDV1a, PI-3V, and BRSV[b]	8/6 and 9/6
		M. haemolytica bacterin-toxoid[c]	8/6
10	11/16	Chemically altered ML BHV-1 and PI-3V, killed BVDV (one BVDV1a and one BVDV1 subtype not specified)[g]	9/1
		Killed BHV-1, BVDV1a, PI-3V, and BRSV	9/28
		M. haemolytica bacterin[l]	
11	11/16	Killed BHV-1, BVDV1a, PI-3V, and BRSV	9/25 and 10/10
		M. haemolytica bacterin[m]	
12	11/16	Chemically altered ML BHV-1 and PI-3V, killed BVDV (one BVDV1a and one BVDV1 subtype not specified)[g]	10/10
		MLV BHV-1[n]	11/5
13	11/16	MLV BHV-1, BVDV1a, BVDV2a, and BRSV[o]	8/21 and 10/02
		P. multocida bacterial extract and *M. haemolytica* toxoid[p]	8/21
		M. haemolytica toxoid[f]	10/16
14	11/16	MLV BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV	9/28 and 10/25
		ML *M. haemolytica* and *P. multocida*[q]	
15	11/16	MLV BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV	9/1 and 9/22
		Leukotoxoid and antigens from *M. haemolytica* and *P. multocida*[r]	
16	11/16	MLV BHV-1, BVDV1a, BVDV2a, PI-3V, and BRSV	10/30 and 11/12
		ML *M. haemolytica* and *P. multocida*[q]	
17	11/16	MLV BHV-1, BVDV1a, PI-3V, and BRSV[b]	10/3 and 10/17
18	11/16	MLV BHV-1, BVDV1a, PI-3V, and BRSV[e]	4/1 and 5/8
		M. haemolytica bacterin-toxoid[c]	11/9

BVDV1a, BVDV2a, PI-3V, and BRSV antibodies;[8,9,10-13] a plaque reduction assay was used to measure the level of BHV-1 antibodies.[8,10-13] Antibodies to *M. haemolytica* whole-cell (WC) antigen, *M. haemolytica* leukotoxin (LKT), and *P. multocida* outer-membrane proteins (OMP) were measured by enzyme-linked immunosorbent assay (ELISA).[3-5]

Statistical Analysis

All data were analyzed using software for statistical analysis.[11] The relationships of morbidity and mortality to herd were analyzed with contingency tables and chi-squared tests.[s] Percentages of calves that were sick or died were compared overall and pairwise to determine which herds differed. Serologic data were analyzed

Table 2. Parameters of performance and health status at delivery for the 291 calves in 18 herds.

Performance parameter	
Shipping weight	At delivery to feedlot
In-value	Price per 100 lb × weight
Total cost	Feed cost + trucking + yardage + options + processing + treatment costs + carcass data + identification
Sickness	Treated once or multiple times
Treatment	No. of treatments
Total treatment costs	Addition of all treatment costs for each animal
Total value	Carcass value
Cost of gain	
Average daily gain (ADG)	
Net value to owner	Carcass value – total cost
Gross margin	Carcass value – total cost – in-value
Health status at delivery	
Organisms for which antibody levels were measured	Bovine herpesvirus-1 Bovine viral diarrhea virus 1a Bovine viral diarrhea virus 2a Bovine respiratory syncytial virus Parainfluenza 3 virus *Pasteurella multocida* outer-membrane protein *Mannheimia haemolytica*, whole cell *M. haemolytica*, leukotoxin
Organisms isolated from nasal swabs	Viruses detected by cell culture Bacteria detected by culture: *P. multocida, M. haemolytica*, and *Histophilus somni*

with analysis of variance (ANOVA) on a per-animal basis.[t] Comparisons for levels of the fixed-factor herd were made with pair-wise T tests if overall comparisons were significant. Each serologic variable was used as a response to the treatment variable herd. Correlations of performance parameters with serologic data were calculated on both a herd and an animal basis.[u] The relationship of individual-animal health, as judged with a binary response (i.e., sick vs not sick), to antibody titers was analyzed by logistic regression.[v]

Results

Vaccination Histories

The cattle delivered included 291 head from 18 different owners. Of the 18 herds, six received KV vaccines (including chemically altered MLV vaccines against BHV-1 and PI-3V), 10 received MLV vaccines, and two used a two-shot combination of killed and MLV vaccines. Viral vaccines contained BHV-1, PI-3V, BVDV1a, and BRSV. There was one exception in that herd 13 excluded the PI-3V vaccine component. Seven of the herds received BVDV2a vaccines, six with a MLV component and one with killed BVDV2a. A total of 13 herds received *M. haemolytica* alone or a *M. haemolytica-P. multocida* combination, and five herds did not receive *M. haemolytica* or *P. multocida* immunogens. Nine herds received a killed or bacterin-toxoid *M. haemolytica-P. multocida* vaccine, and four herds received a modified-live (ML) *M. haemolytica-P. multocida* vaccine.

Morbidity and Mortality

There were 126 of 291 (43.3%) calves treated for respiratory disease (Table 3). Seven calves died with signs of respiratory disease and two died with clinical signs of enterotoxemia (nine head total) for a total mortality rate of 3.1%. Three calves were removed during the feeding period as "realizers", one each from herds 1, 3, and 8. Realizers were sold before optimum market time with conditions permitting processing and passage of inspection (antemortem and post processing); withdrawal time for medications had elapsed.

Morbidity rates (43.3% overall) differed among the 18 herds (Table 3). Herds 1, 3, and 18 had significantly

Table 3. Herd morbidity and mortality.

		Morbidity		Mortality	
Herd no.	No. of calves	No. sick	% of calves	No. of calves	% of calves
1	86	21	24.4[d*]	1 - pneumonia	2.3
2	5	4	80.0[a]	0	0.0
3	18	5	27.8[cd]	1 - pneumonia	5.6
4	10	5	50.0[abcd]	0	0.0
5	19	14	73.7[a]	2 - pneumonia - enterotoxemia	10.5
6	8	5	62.5[abc]	0	0.0
7	5	4	80.0[a]	1 - pneumonia	20.0
8	12	10	83.3[a]	0	0.0
9	10	6	60.0[abc]	1 - enterotoxemia	10.0
10	27	12	44.4[abcd]	2 - pneumonia	7.4
11	20	7	35.5[bcd]	0	0.0
12	10	4	40.0[abcd]	0	0.0
13	10	5	50.0[abcd]	0	0.0
14	10	4	40.0[abcd]	0	0.0
15	14	8	57.1[abc]	0	0.0
16	7	3	42.9[abcd]	0	0.0
17	10	7	70.0[ab]	1 - pneumonia	10.0
18	5	0	0.0[d]	0	0.0
Total	291	126	43.3%	9	3.1%

*Within the column, herds with same superscript letter are not significantly different ($P<0.05$)

lower morbidity rate ($P<0.05$) than herds 2, 5, 7, 8, and 17. Herds 1 and 18 had lower morbidity rate ($P<0.05$) than herds 6 and 15.

Bacterial and Viral Isolation and Lesions

At entry into the ROP at processing, *M. haemolytica* was isolated from the nasal passages of 23 of the 291 calves (8.0%). These were found in 11 of the 18 herds (61.1%). No calves were culture-positive for *P. multocida* or *H. somni*. No viruses were isolated from the nasal swabs or PBL collected at processing, thus no PI BVDV calves were present in this study. Presence of bacteria in the nasal swabs at entry did not predict illness or performance parameters. Likewise, absence of detectable virus at entry from nasal swabs or PBL was not a predictor of illness or performance parameters.

Lungs collected from calves dying of respiratory disease were examined for lesions of pneumonia, and isolation attempts were made for bacterial (including *Mycoplasma* spp) and viral agents from homogenates of lung tissue (Table 4). The lesions ranged from acute to chronic in duration and included fibrinopurulent and bronchopneumonia lesions typical of BRD. Fatal respiratory disease cases died between 19 and 140 days after arrival. Three of the seven lungs were culture-positive for *M. haemolytica*, four with *P. multocida*, and one with *Arcanobacterium pyogenes*. Two of the seven calves were positive for both *M. haemolytica* and *P. multocida*, and six were positive for *Mycoplasma* spp. All lungs were negative for viruses by cell culture isolation attempts from lung homogenates.

Serologic Findings

Mean titers to the five viral and three bacterial antigens are listed in Table 5. The mean titers were compared among the 18 herds. Viral titers were expressed as geometric means, and bacterial antibody quantities as arithmetic means. There were significant differences among herds for antibodies to each antigen ($P<0.05$). In general, those herds with the highest quantity to *M. haemolytica* WC were those receiving vaccines with *M. haemolytica* immunogens. Herds 1, 3, 11, and 18 received *M. haemolytica* vaccines and had higher quantity ($P<0.05$) than herds 4, 5, 7, 12, and 17 not receiving *M. haemolytica* vaccines. There were exceptions, as herd 10 received a *M. haemolytica* vaccine and had *M. haemolytica* WC quantity as low as the *M. haemolytica* non-vaccinates.

Herds 1, 3, and 18 receiving *M. haemolytica* vaccines had higher *M. haemolytica* LKT quantity than

Table 4. Respiratory tract lesions of bacterial, mycoplasma, and viral isolation results from calves dying during the study.

Animal no.	Day of death	Type of pneumonia histopathology	Bacteria isolated	*Mycoplasma* spp isolated	Viruses isolated
199	140	Acute, moderate to severe, fibrinopurulent pleuropneumonia with peribronchiolar lymphoid nodular hyperplasia	*M. haemolytica* *P. multocida*	Yes	No
374	25	Acute, severe, fibrinopurulent, pleuropneumonia with necrotizing bronchiolitis and acute suppurative arteritis	*Arcanobacterium pyogenes*	Yes	No
108	19	Severe, diffuse, subacute, suppurative bronchopneumonia	*P. multocida*	Yes	No
274	46	Subacute, mild to moderate, diffuse, lymphoplasmacytic interstitial pneumonia	None	Yes	No
241	22	Acute, severe, fibrinopurulent pleuropneumonia	*M. haemolytica* *P. multocida*	No	No
228	68	Chronic severe fibrinopurulent pleuropneumonia with bronchiolar dilation	*P. multocida*	Yes	No
276	123	Chronic severe fibrinopurulent pleuropneumonia with severe fibrosis and abscessation. Chronic, diffuse, lymphoplasmacytic tracheitis with focal abscessation and caseous necrosis	*M. haemolytica*	Yes	No

Table 5. Antibodies to viruses and bacteria at time of entry*.

Herd no.	N	Mh WC	Mh LKT	Pm OMP	BVDV1a	BVDV2a	BHV-1	PI-3V	BRSV
1	86	0.81777^{e}	0.55071^{de}	0.66687^{c}	454^{ef}	101^{g}	126^{d}	160^{g}	29^{ef}
2	5	0.16640^{abc}	0.29080^{abcd}	0.27780^{abc}	12^{a}	0^{a}	47^{c}	8^{cde}	11^{abcd}
3	18	0.85039^{e}	0.86711^{e}	1.5739^{de}	1448^{g}	45^{ef}	59^{c}	84^{f}	29^{def}
4	10	0.33680^{abc}	0.70060^{e}	0.51627^{abc}	104^{c}	3^{ab}	48^{c}	362^{h}	37^{efg}
5	19	0.20663^{abc}	0.25626^{abc}	0.09189^{a}	275^{def}	319^{h}	143^{d}	10^{de}	23^{cde}
6	8	0.10913^{ab}	0.13538^{a}	0.59113^{bc}	64^{bc}	117^{gh}	5^{a}	4^{abc}	117^{g}
7	5	0.05820^{ab}	0.07900^{a}	0.20920^{abc}	8^{a}	3^{ab}	35^{bc}	42^{f}	14^{abcde}
8	12	0.48883^{bcd}	0.67708^{de}	0.37267^{abc}	29^{ab}	3^{ab}	54^{c}	40^{f}	20^{bcde}
9	10	0.06230^{ab}	0.15470^{a}	0.19360^{ab}	194^{cde}	18^{de}	10^{a}	5^{bcd}	11^{abc}
10	27	0.02878^{a}	0.19633^{a}	0.30274^{abc}	102^{c}	3^{ab}	55^{c}	396^{h}	37^{efg}
11	20	0.68310^{de}	0.50750^{cde}	0.45170^{abc}	14^{a}	1^{a}	27^{bc}	375^{h}	5^{a}
12	10	0.13350^{ab}	0.25330^{abc}	1.44460^{ef}	23^{ab}	4^{bc}	89^{cd}	2^{ab}	10^{ab}
13	10	0.27110^{abc}	0.36820^{abcd}	0.50020^{abc}	64^{bc}	274^{h}	56^{c}	1^{a}	84^{g}
14	15	0.55453^{cd}	0.49280^{bcde}	1.35933^{ef}	354^{def}	223^{h}	138^{d}	40^{f}	51^{fg}
15	14	0.42864^{bcd}	0.36536^{abcd}	0.71893^{c}	1521^{g}	55^{fg}	6^{a}	3^{abc}	5^{a}
16	7	0.19314^{abc}	0.72443^{e}	0.78871^{cd}	345^{def}	13^{cd}	171^{d}	53^{f}	24^{cde}
17	10	0.12770^{ab}	0.20540^{ab}	1.76150^{f}	128^{cd}	11^{cd}	92^{cd}	42^{f}	9^{ab}
18	5	0.75380^{de}	1.55200^{f}	0.29420^{abc}	1024^{fg}	32^{def}	13^{ab}	28^{ef}	7^{efg}

*Within the same column, mean titers with same superscript letter are not significantly different ($P<0.05$).
Anti-viral titers expressed as geometric means and anti-bacterial concentrations expressed as arithmetic mean of ng of immunoglobulin binding.

herds 5, 7, 12, and 17 not receiving *M. haemolytica* vaccines. There were exceptions as herd 4 received no *M. haemolytica* vaccine and had high quantity to *M. haemolytica* LKT that was not different statistically from herds 3 and 16 receiving *M. haemolytica* vaccines.

The antibody quantity to the *P. multocida* OMP antigen was not always related to vaccine status. In some cases vaccines did not induce detectable antibodies, whereas in other cases natural infections stimulated higher antibody quantities. For example, herd 17 not

receiving *P. multocida* vaccine had the highest antibody quantity to *P. multocida* OMP, and had higher quantity than herds 6 and 16 ($P<0.05$) that received a ML vaccine with *P. multocida*, and herd 13 that received a *P. multocida* bacterial extract ($P<0.05$).

In general, antibody titers to BVDV1a were lower in those herds receiving a killed BVDV vaccine than MLV BVDV1a vaccine. Herds 7, 8, 11, and 12 that received killed BVDV1a vaccine had lower BVDV1a titers than herds 1, 3, 5, 9, 14, 15, 16, and 18 ($P<0.05$) that received MLV BVDV1a. Herds 4 and 10 that received killed BVDV1a vaccine had lower BVDV1a titers than those receiving MLV BVDV1a vaccine (herds 1, 3, 5, 9, 14, 15, 16, and 18) ($P<0.05$).

Higher antibody titers to BVDV2a were reflected in herds receiving vaccines containing BVDV2a. Herds 1, 5, 6, 13, and 14 received BVDV2a vaccines and had higher BVDV2a titers ($P<0.05$) than herds 2, 4, 7, 8, 10, 11, 12, and 17 that received no BVDV2a vaccines.

The antibody titers to BHV-1 based on MLV or killed (including chemically altered ML BHV-1) vaccine usage were not clearly differentiated. The three herds with the lowest BHV-1 titers (herds 6, 9, and 15) had received MLV vaccines. Five herds that received killed or chemically altered ML BHV-1 had higher BHV-1 titers than the three herds with low BHV-1 titers that received MLV BHV-1 vaccine ($P<0.05$).

The antibody titers to PI-3V did not indicate a predominance of MLV vaccine use over the killed vaccines, including chemically altered ML PI-3V. Even among herds receiving the chemically altered PI-3V there were differences, with herds 4, 8, and 10 having higher PI-3V titers ($P<0.05$) than herd 12. The lack of PI-3V immunogen in a vaccine was noted as herd 13 received no PI-3V vaccine and had the lowest PI-3V antibody titers.

A wide range of titers to BRSV occurred among the 18 herds. Only two herds, 7 and 10, received a killed BRSV vaccine, with the remaining 16 herds receiving MLV BRSV vaccine. Even among herds receiving MLV BRSV there was a wide range of titers. For example herd 15, which was vaccinated with MLV BRSV, had the lowest BRSV titer (5) compared to others receiving MLV BRSV, such as herd 10.

Animal Health at Entry Versus Subsequent Feedlot Performance

There were substantial differences in the treatment costs per animal on a herd basis (Table 6). Three herds (1, 3, and 18) had significantly lower treatment costs ($0.00 to $3.42) than six herds (2, 5, 6, 7, 8, and 17) ($P<0.05$). The three herds with the lowest treatment costs had received a vaccine containing *M. haemolytica*, whereas only three of the six with higher treatment costs had received *M. haemolytica* vaccine (herds 2, 6, and 8). There were differences among the herds (Table 7) for

Table 6. Total treatment costs per animal on a herd basis.

Herd no.	Mean costs ($)[x]
18	0.00[a]
1	2.6473[a]
3	3.4156[a]
4	6.1710[ab]
14	6.6687[ab]
11	6.6870[ab]
12	7.00[ab]
13	7.6890[ab]
10	7.7893[ab]
9	8.1230[ab]
15	8.2121[ab]
16	9.8086[abc]
5	10.1247[bc]
6	10.6863[bc]
8	13.6233[bc]
7	14.0800[bc]
2	14.9720[bc]
17	17.4530[c]

[x]Means with the same superscript letter are not significantly different ($P<0.05$).

Table 7. Net value to owner per animal on a herd basis.

Herd no.	Mean value ($)[x]
7	295.532[a]
5	319.697[a]
2	391.294[ab]
9	398.792[ab]
13	401.743[ab]
1	401.865[ab]
17	423.569[ab]
10	424.914[ab]
8	446.138[bc]
4	453.575[bc]
18	454.236[bc]
11	463.931[bc]
3	477.086[bc]
12	485.691[bc]
6	485.996[bc]
15	488.947[bc]
16	506.776[bc]
14	533.575[c]

[x]Means with same superscript letter are not significantly different ($P<0.05$).

the net value to owner for the feedlot interval. The net value to owner is defined as the financial return from carcass value minus total costs in the feedlot. The net value to owner per animal on a herd basis ranged from $295.53 to $533.58. Herds 7 and 5 had significantly lower net value ($295.53 and $319.70, respectively) compared to herds 3, 4, 6, 8, 11, 12, 14, 15, 16, and 18 ($446.14 to $533.58) ($P<0.05$). All herds had received viral vaccines, however, there were differences in the use of *M. haemolytica* and *P. multocida* vaccines in that the two herds (7 and 5) with the lowest net value to owner had not received *M. haemolytica* or *P. multocida* immunogens. For the 10 herds returning the highest net value to the owner, eight herds received bacterial vaccine (four with *M. haemolytica* only [inactivated], one received *M. haemolytica* and *P. multocida* inactivated, and three received ML *M. haemolytica* and *P. multocida*) with two of the 10 herds receiving no *M. haemolytica* or *P. multocida* immunogens.

Mean number of treatments per animal differed on a herd basis (Table 8). Three herds, 1, 3, and 18, had a significantly lower number of treatments (0.0 to 0.39) than herds 2, 5, 7, 8, and 17 (1.0 to 1.4) ($P<0.05$). Those three herds with the lowest mean treatments had received *M. haemolytica* immunogens, whereas of the five herds with the most treatments, three had no *M. haemolytica* or *P. multocida* vaccines while two herds had received a *M. haemolytica* vaccine.

Table 8. Mean number of treatments per animal on a herd basis.

Herd no.	Number of treatments (Mean)[x]
18	0.00^{a}
1	0.31395^{a}
3	0.38889^{ab}
12	0.50^{abc}
14	0.53333^{abc}
16	0.57143^{abcd}
11	0.60^{abcd}
4	0.60^{abcd}
10	0.62963^{abcd}
9	0.70^{abcd}
13	0.77778^{abcd}
6	0.87500^{abcd}
15	0.92857^{bcd}
5	1.00^{cd}
8	1.25^{d}
17	1.30^{d}
7	1.40^{d}
2	1.40^{d}

[x]Means with the same superscript letter are not significantly different ($P<0.05$).

The significant relationship between health status at entry and feedlot performance utilizing serum antibody titers at entry are summarized in Table 9. The analysis was performed on an individual animal basis and on a herd average (average for all animals in that herd's shipment). For individual animals, low antibody titers to *M. haemolytica* WC, BVDV1a, BHV-1, and PI-3V were associated with illness (morbidity) with one or more treatments ($P<0.05$). Low antibodies to *M. haemolytica* WC, BVDV1a, BHV-1, PI-3V, and BRSV were associated with increased number of treatments ($P<0.05$). Low antibodies for BVDV2a approached significance ($P=0.0943$) for increased number of treatments. Low antibody titers for *M. haemolytica* LKT and WC, BVDV1a, BVDV2a, and PI-3V were associated with increased treatment costs ($P<0.05$). Low antibody titers to BRSV approached significance ($P=0.0840$) for increased total treatment costs. Low antibody titers to *P. multocida* OMP and *M. haemolytica* LKT were associated with decreased net value to owner ($P<0.05$). Also, increased number of treatments and total treatment costs were associated with reduced net value to owner ($P<0.05$).

Using herd average for the 18 herds, there were differences among the various parameters. Low antibodies to BVDV1a were associated with sickness (one or more treatments) ($P<0.05$); however, low BHV-1 antibody titers were not associated with sickness but approached significance ($P=0.0928$). Low *P. multocida* OMP antibody concentrations were associated with reduced net value to owner ($P<0.05$), and an increased number of treatments ($P<0.05$). Low antibody titers to *M. haemolytica* LKT, *M. haemolytica* WC, and BVDV1a were associated with increased number of treatments ($P<0.05$). Low antibody concentrations to *M. haemolytica* LKT and *M. haemolytica* WC, and increased number of treatments were associated with increased treatment costs ($P<0.05$).

Discussion

This study investigated the impact of health status of calves at entry on feedlot performance. Health status was based on serum antibody levels to several pathogens collected at initial processing on the calves direct from the ranch. Results indicate an association between vaccination histories, antibody concentrations, and performance. There were no unvaccinated calves from each of the herds along with the vaccinated calves. Potentially there may have been field exposure to the infections in the herds stimulating antibody production. A prior study was the inaugural phase of the ROP research project with calves delivered in the fall of 2000, and held in the feedlot from November 2000 till harvest processing during the summer of 2001.[11] In that initial study, certain predictors of feedlot performance were recognized, primarily the beneficial effect of higher

Table 9. Significant relationships between health status and performance.

For Individual Animals	
Sickness	Low *M. haemolytica* whole cell titer (P=0.005)
	Low BVDV1a titer (P=0.0003)
	Low BHV-1 titer (P=0.0162)
	Low PI-3V titer (P=0.0019)
Decreased net value to owner	Low *P. multocida* OMP titer (P=0.0160)
	Low *M. haemolytica* leukotoxin titer (P=0.0789)
	Increased number of treatments (P 0.0002)
	Increased total treatment costs (P<0.0001)
Increased number of treatments	Low *M. haemolytica* whole cell titer (P=0.0030)
	Low BVDV1a titer (P=0.0016)
	Low BVDV2a titer (P=0.0943)
	Low BHV-1 titer (P=0.0496)
	Low PI-3V titer (P=0.0018)
	Low BRSV titer (P=0.0408)
	Low *M. haemolytica* leukotoxin titer (P=0.0950)
Increased total treatment costs	Low *M. haemolytica* whole cell titer (P=0.0009)
	Low BVDV1a titer (P=0.0003)
	Low BVDV2a titer (P=0.0172)
	Low PI-3V titer (P=0.00070)
	Low BRSV titer (P=0.0840)
Herd Averages	
Sickness	Low BVDV1a titer (P=0.0161)
	Low BHV-1 titer (P=0.0928)
Decreased net value to owner	Low *P. multocida* OMP titer (P=0.0175)
	Increased number of treatments (P=0.0398)
Increased number of treatments	Low *M. haemolytica* leukotoxin titer (P=0.0044)
	Low *M. haemolytica* whole cell titer (P=0.0129)
	Low BVDV1a titer (P=0.0140)
Increased total treatment costs	Low *M. haemolytica* leukotoxin titer (P=0.0050)
	Low *M. haemolytica* whole cell titer (P=0.0026)
	Increased number of treatments (P=0.006)

antibody levels to selected viral and bacterial BRD pathogens. Following that study, recommendations were made including addition of BVDV2a immunogen to the viral vaccines containing BHV-1, PI-3V, BVDV1a, and BRSV. Also greater emphasis was placed on the use of *M. haemolytica* and *P. multocida* vaccines.

In the present study a shift in the type of vaccines used in the ROP after the recommendations was noted. For this second study there were 18 ranches with six using KV vaccines (33.3%), 10 receiving MLV viral vaccines (55.6%), and two using a two-shot combination of killed and MLV vaccines (11.1%). This compares to the initial study where 10 of 24 herds used KV vaccines (41.7%), nine received MLV vaccines (37.5%), and five received the two-shot killed and MLV combination (20.85%). While the number of herds is not particularly large, there appears to be an upward trend (almost 20%) for increased use of MLV vaccines. In addition, in this study, seven herds (38.9%) used BVDV2a in addition to BVDV1a compared to seven of 24 (29.2%) in the prior study. Of those vaccinating with BVDV2a, MLV BVDV2a was used in six of seven herds compared to none of seven in the prior study. This is likely due both to veterinarian's recommendation and marketing efforts by the biologics companies.

A shift occurred in the use of *M. haemolytica* and *P. multocida* vaccines in the present study compared to the previous one. In the initial study, 10 of 24 (41.7%) used bacterial vaccines with *M. haemolytica* or *M. haemolytica-P. multocida* combination, and all 10 vaccines were inactivated. In the current study, 13 of 18 (72.2%) used *M. haemolytica* or *M. haemolytica-P. multocida* combination for a 30% increase in the use of these vaccines. Of these 13 herds, ML *M. haemolytica-P. multocida* vaccine was used in four herds, whereas ML vaccine was not used in the prior study. Again, availability of the ML vaccine plus veterinarian's recommendations most likely account for its use.

Ideally, the recommendations for vaccinations would have resulted in less morbidity and mortality.

However, in the prior study there was a 27.3% morbidity rate and 0.96% mortality rate, in contrast to calves in the current study with a 43.3% morbidity rate and 3.43% mortality rate. The cattle in both studies went to the same feedlot in November of the respective years. Potentially there may have been variation in subjective criteria used to identify and pull the cattle from the pen for treatment, a potential increase in virulence of the bacteria causing BRD, changes in response to antimicrobials, as well as possible increased stressors, such as climate. Regardless of the changes in morbidity and mortality between the two studies, variations in morbidity, number of treatments, treatment costs, and net value to the owner were seen both on an individual and a herd basis.

Analyses of antibody titers to several BRD pathogens for their prediction of several performance parameters was again rewarding for this educational program. The lower antibody levels to BVDV1a and 2a, *M. haemolytica*, and *P. multocida* antigens were again predictors of selected production parameters.[11] In this study there were instances where lower BHV-1, PI-3V, and BRSV antibody levels were also predictive of increased health risk.

While each rancher and their veterinarian develop a vaccination program applicable to each ranch's management system, there will likely be greater emphasis of MLV vaccines. Recommendations for future studies center on continued use of available viral vaccines and the *M. haemolytica-P. multocida* vaccines, especially administering the vaccines prior to feedlot entry. Continued emphasis will be placed on addition of BVDV2a to the viral vaccines. Results of the prior study and the current one reinforce that higher antibody levels to selected pathogens should benefit the cattle with less illness (morbidity) and treatment, and can potentially increase economic return.

In summary, this study attempted to determine whether there were certain predictors, such as antibody levels to five viruses and two bacteria, of feedlot performance. This second study was again successful in demonstrating that increased antibody levels to BHV-1 BVDV1a, BVDV2a, PI-3V, BRSV, *M. haemolytica*, and *P. multocida* prior to feedlot entry were beneficial to the calf. Several management factors were used to improve animal health and feedlot performance including dehorning horned calves, castration of male calves, anthelmintic treatment, holding calves postweaning 30-45 days, and vaccination including viral and bacterial immunization products. While it may be difficult to single out one or a combination of these management practices, this study's results reaffirm that post-weaning calves with increased immunity to BHV-1, BVDV, PI-3V, BRSV, *M. haemolytica,* and *P. multocida* after vaccination perform better in the feedlot with less clinical disease caused by these BRD pathogens, and provide greater economic return to the owner. Admittedly there were herds with low numbers of calves entered into the study, yet statistical analysis using both individual animals and herd averages did demonstrate the effects of lower levels of antibodies. There are vaccines available in the US to provide immunity to these viruses and bacteria. While there may be questions of efficacy of selected vaccines, continued vigilance for their use and further development and/or improvement of vaccines is in order.

Conclusions

Results of this study reaffirm that post-weaning calves with increased immunity as measured by antibody levels to BVDV1a, BVDV2a, BHV-1, PI-3V, BRSV, *M. haemolytica*, and *P. multocida* after vaccination perform better in the feedlot and have less clinical disease caused by these BRD pathogens, and provide greater economic return to the owner as well. Management for the breeding cow-herd owner retaining calves for feedlot delivery should stress vaccination against these pathogens with sufficient time to develop immunity before shipping calves to the feedlot or commingling with other cattle.

Endnotes

[a]Triangle® 9+Type II BVD, Fort Dodge Animal Health, Fort Dodge, IA
[b]BoviShield 4™, Pfizer Inc., Animal Health Group, New York, NY
[c]One Shot®, Pfizer Inc., Animal Health Group, New York, NY
[d]TSV-2, Pfizer Inc., Animal Health Group, New York, NY
[e]Pyramid® 4 MLV, Fort Dodge Animal Health, Fort Dodge, IA
[f]Presponse® SQ, Fort Dodge Animal Health, Fort Dodge, IA
[g]CattleMaster® 4, Pfizer Inc., Animal Health Group, New York, NY
[h]Titanium™ 5, AgriLaboratories, St. Joseph, MO
[i]Titanium 5®+PHM Bac®1, AgriLaboratories, St. Joseph, MO
[j]Titanium™ BRSV, AgriLaboratories, St. Joseph, MO
[k]Elite 4™, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO
[l]Triangle 4®+ PHK, Fort Dodge Animal Health, Fort Dodge, IA
[m]Triangle 9®+ PHK, Fort Dodge Animal Health, Fort Dodge, IA
[n]Titanium™ IBR, AgriLaboratories, St. Joseph, MO
[o]Frontier™ F3LP Plus, Intervet Inc., Millsboro, DE
[p]Presponse® HM, Fort Dodge Animal Health, Fort Dodge, IA

[q]4 Once Plus™, Intervet Inc., Millsboro, DE
[r]Express™ 5 PHM, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO
[s]PROC FREQ SAS. Version 8.2. SAS for Windows, SAS Institute Inc., Cary, NC
[t]PROC MIXED SAS. Version 8.2. SAS for Windows, SAS Institute Inc., Cary, NC
[u]PROC CORR SAS. Version 8.2. SAS for Windows, SAS Institute Inc., Cary, NC
[v]PROC LOGISTIC. Version 8.2. SAS for Windows, SAS Institute Inc., Cary, NC

Acknowledgements

This study was funded by a grant from The Noble Foundation, Ardmore, OK, and the Oklahoma Agriculture Experiment Station, Oklahoma State University, Stillwater, OK. The support of the cooperating ranchers in the Retained Ownership Program for The Noble Foundation and the commercial feedlot is greatly appreciated.

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