Evaluation of an autogenous *Salmonella* bacterin and a modified live *Salmonella* serotype Choleraesuis vaccine on a commercial dairy farm

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Objective—To compare the efficacy of a *Salmonella* bacterin and a modified live *Salmonella* ser. Choleraesuis vaccine on a commercial dairy.

Animals—450 cows in late gestation and 80 calves.

Procedure—Group-1 cows (n = 150) were vaccinated once with a modified live *S* Choleraesuis (serogroup C1) strain 54 (SC54) vaccine, group-2 cows (150) were vaccinated on enrollment and 30 days later with a *Salmonella* ser. Montevideo (serogroup C1) bacterin, and group-3 cows (150) served as unvaccinated controls. One gallon of colostrum harvested from the first 80 cows to calve was fed to each calf. Outcome assessments included fecal shedding of *Salmonella* spp for the first 10 days after parturition (cows) or birth (calves), milk production, involuntary culling rate, mastitis incidence, antimicrobial use, and mortality rate.

Results—Salmonellae were isolated from 306 of 309 (99%) cows and 64 of 74 (86.5%) calves. Shedding frequency was less in SC54-vaccinated cows and calves that received colostrum from those cows, compared with the other groups, and vaccination was specifically associated with less shedding of serogroup C1 salmonellae. Production data were similar among groups.

Conclusions and Clinical Relevance—Vaccination of pregnant cows with an autogenous *Salmonella* bacterin had no effect on fecal shedding of salmonellae, whereas vaccination with a modified live *S* Choleraesuis vaccine reduced the frequency of fecal shedding of serogroup C1 salmonellae during the peripartum period. A commercial *S* Choleraesuis vaccine licensed for use in swine may be more efficacious than autogenous *Salmonella* bacterins on dairies infected with serogroup C1 salmonellae. (*Am J Vet Res* 2001;62:1897–1902)

Salmonella spp are common infectious enteric bacterial pathogens of dairy cattle, and salmonellosis is one of the most common zoonotic diseases associated with human consumption of beef and dairy products.[1,2] Although most *Salmonella* infections in cattle are subclinical, clinical disease may be precipitated by stressful events that compromise host immunity, exposure to an overwhelming challenge dose, or introduction of a virulent serotype into a naïve population. Epidemiologic evidence indicates the prevalence of *Salmonella* spp is 16 to 27% on US dairy farms and as high as 73% on dairies in California, the largest milk producing state in the nation.[3-5] A recent survey[6] of 91 US dairy herds identified large herd size, use of flush water systems to dispose of waste, region, and feeding brewers' products to lactating cows as the most important predictive risk factors for isolation of *Salmonella* spp. Although numerous risk factors for salmonellosis in dairy cattle have been proposed, the variables and their interactions that contribute to the persistence of *Salmonella* spp on dairy farms are poorly understood. Development of effective strategies to prevent *Salmonella* infections of livestock is important not only for animal welfare but also to reduce production losses and the risk of human disease associated with the consumption of beef and dairy products.

Calves exposed to low doses of virulent *Salmonella* spp are protected against subsequent high-dose virulent challenge.[7,8] This suggests that prevention of salmonellosis is possible via vaccination. Numerous *Salmonella* vaccines, including bacterins and subunit and attenuated modified live vaccines, have been evaluated in calves, using virulent challenge models. Results of comparative vaccine trials indicate that modified live attenuated *Salmonella* vaccines provide greater protection against challenge with virulent *Salmonella* spp than do *Salmonella* bacterins.[9-12] Benefits observed in experimentally challenged vaccinated calves include reduced fecal shedding of salmonellae, decreased severity of disease, and reduced mortality. Until recently, only *Salmonella* bacterins have been licensed for use in cattle in the United States. In January 2000, a genetically altered modified live *Salmonella* ser. Dublin vaccine was licensed for use in calves. Most of the *Salmonella* bacterins comprise either *Salmonella* ser. Typhimurium and *S* Dublin together or *S* Typhimurium alone. *Salmonella* Typhimurium (serogroup B) and *S* Dublin (serogroup D) are the 2 serotypes most commonly isolated from cattle with salmonellosis in the United States. Although *Salmonella* from serogroups C and E are also

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commonly isolated from infected cattle, there are no vaccines licensed for use in cattle to prevent disease caused by these serogroups. It is common practice in the United States for managers of dairy farms with cows infected with serotypes other than *S* Typhimurium or *S* Dublin to vaccinate cows with an autogenous *Salmonella* bacterin. Despite several empirical reports describing the administration of *Salmonella* bacterins in *Salmonella*-infected herds,[13] there have been no controlled clinical trials of *Salmonella* bacterins in adult cattle. The objective of the study reported here was to evaluate the effects of an autogenous *Salmonella* bacterin and a modified live *Salmonella* ser. Choleraesuis vaccine administered to dairy cows during late pregnancy on fecal shedding of *Salmonella* organisms during the peripartum period, on productivity, culling, and mortality during the subsequent lactation period, and on fecal shedding of salmonellae by calves during the first 10 days of life.

Materials and Methods

Study population—Four hundred fifty cows and 80 calves on a commercial dry lot dairy were included in the study. This dairy milked 9,000 cows with a rolling herd average of 21,000 lb of milk. Colostrum was harvested from the first 80 cows in the study to calve. At birth, calves were fed a gallon of harvested colostrum and assigned the same group designation as the cow from which the colostrum was obtained.

Vaccine selection and preparation—Prior to initiation of this study, fecal swab specimens were collected from cows and calves at different stages in the production cycle to determine the prevalence of fecal shedding of *Salmonella* organisms. *Salmonella* spp were isolated from 36 of 120 (30%) fecal swab specimens collected from nonlactating cows, 48 of 120 (40%) specimens collected from peripartum cows, and 60 of 120 (50%) specimens collected from calves < 14 days old. *Salmonella* serotypes isolated from all groups of cattle in order of decreasing frequency were *S* Montevideo (serogroup C1; isolated from 82/130 [63%] specimens), *S* Kentucky (serogroup C3; 21/130 [16.2%]), *S* Cerro (serogroup K; 8/130 [6.2%]), *S* Anatum (serogroup E1; 6/130 [4.6%]), *S* Havana (serogroup G2; 3/130 [2.3%]), *S* Sandiego (serogroup B; 2/130 [1.5%]), *S* Agona (serogroup B; 1/130 [0.8%]), *S* Senftenberg (serogroup E4; 1/130 [0.8%]), and *S* Typhimurium (serogroup B; 1/130 [0.8%]). In addition, an untypable rough strain was isolated from 5 of 130 (3.8%) specimens. The serotype of the 2 vaccines used in this study was selected to match the serogroup (serogroup C1) of the most common *Salmonella* serotype (*S* Montevideo) isolated from fecal swab specimens.

Autogenous bacterin preparation—*Salmonella* Montevideo isolated from feces of a cow on the dairy was used to prepare an autogenous *S* Montevideo bacterin. The bacterin was prepared according to a described method[14] with modification of the adjuvant. Briefly, 8 L of trypticase soy broth was inoculated with a single colony of *S* Montevideo and incubated at 37 C for 18 hours. Number of **colony forming units** (**CFU**)/ml was determined by serial dilution of bacterial cultures in isotonic saline (0.9% NaCl) solution and plating 100-µl aliquots of diluted cultures on brilliant green agar. *Salmonella* organisms in the original culture were harvested by centrifugation. The pellet was washed with PBS solution containing 0.3% formalin and recentrifuged. The supernatant was discarded, and the wash and centrifugation steps were repeated twice. Bacteria were then suspended in 1,500 ml of alhydrogel[a] and 30 mg of Quill A.[b] Each 5-ml dose of the resulting bacterin contained 2.5×10^{10} CFU of *S* Montevideo, 100 µg of $Al(OH)_3$, and 100 µg of Quill A. Sterility of the bacterin was verified via plating on blood agar and *Salmonella* enrichment culture.

Modified live *Salmonella* vaccine—The commercial modified live *S* Choleraesuis strain 54 vaccine,[c] which is licensed for use in swine, was selected for testing on the basis of its serogroup (C1) and reported efficacy at reducing severity of disease and frequency of fecal shedding of organisms in calves challenged with *S* Dublin.[15] *Salmonella* Choleraesuis strain 54 was derived from virulent *S* Choleraesuis strain 38 by repeated passage through porcine neutrophils.[16] Prior to the study, 5 cows in late gestation received an IM injection of 2 ml of the vaccine on the side of the neck to determine whether this vaccine elicited adverse reactions. All of the cows developed transient fevers (rectal temperature, 39.5 to 40.5 C) for 24 to 48 hours. No other adverse reactions were observed.

Vaccination protocol—Four hundred fifty nonlactating cows between 225 and 235 days in gestation were enrolled in the study over a 4-week period. As cows were enrolled in the study they were randomly allocated to 1 of 3 groups (150 cows/group). Group-1 cows (SC54 group) were vaccinated once on enrollment with the modified live *S* Choleraesuis strain 54 vaccine, and group-2 cows (bacterin group) were vaccinated once on enrollment and again 30 days later with the autogenous *Salmonella* bacterin. Group-3 cows (control group) were not vaccinated. Both vaccines were administered via IM injection in the neck. In addition, vaccines were administered when the ambient temperature was < 30 C to avoid adverse endotoxin-associated reactions.

Culture of fecal samples for *Salmonella spp*—Fecal swab specimens were collected daily from cows and calves for 10 days. Sample collection was initiated from cows on the day following parturition and from calves on the day following birth. Specimens were collected by inserting a sterile cotton-tipped applicator into the rectum of each animal. The rectal swab was placed into 10 ml of tetrathionate broth, incubated for 24 hours at 37 C, and then plated onto brilliant green agar. Brilliant green agar plates were incubated for 24 hours at 37 C. Suspect colonies were subcultured to achieve a pure growth and tested, using triple sugar iron,[d] urea,[e] and O-nitrophenyl-β-D-galactopyranoside[f] biochemical tests. Those isolates with reactions typical of *Salmonella* spp were tested for agglutination with commercial polyvalent and O-group specific antisera.[g] Twenty-five isolates from each serogroup isolated were sent to the National Veterinary Services Laboratory[h] for serotyping.

Collection and administration of colostrum—Colostrum from the first 80 cows to calve was harvested and fed to 80 calves to evaluate the effect of feeding colostrum from vaccinated cows on fecal shedding of *Salmonella* spp by calves. Each group was assigned a color to allow tracking of colostrum harvested from cows in that group. Colostrum was harvested from cows within 6 hours of parturition, placed in 2-qt bottles labeled with a colored sticker, and refrigerated until fed to calves. Calves were randomly allocated to treatment groups. Calves were not fed colostrum harvested from their dam. Each calf received 1 gal of colostrum (ie, two 2-qt bottles of the same color) via an esophageal feeder within 6 hours of birth. Passive transfer was evaluated when calves were 48 hours old by measuring total serum protein concentration, using a temperature-compensated refractometer.

Statistical analyses—Data from the subsequent lactation (305 days) regarding milk production, mortality rate,

medical treatment, reproductive performance, and culling rate for cows and calves enrolled in the study were extracted from the Dairycomp 305 herd records. Milk production (ie, mean **mature equivalent milk production [ME 305]**) and mean number of days of antimicrobial treatment were compared among groups by use of ANOVA. Proportional comparisons were performed, using the χ^2 test. Time-dependent variables (eg, days to pregnancy) were compared among groups by use of Cox regression analysis. For all statistical analyses, significance was set at $P \leq 0.05$.

Results

Five or more fecal swab specimens were collected from 309 of the 450 (68.7%) cows and 74 of the 80 (92.5%) calves enrolled in the study. Missing specimens reflected animals that died, failure to locate cows, or difficulties in catching cows. Rain and muddy conditions compromised specimen collection for 2 weeks of the 8-week sampling period. Missing specimens were distributed evenly across the 3 groups. Late-term abortions were reported for 3 of the 450 cows. In addition, 9 cows died within 10 days of parturition, and 11 cows failed to calve during the collection period. Nine of the 80 calves died within 10 days of birth. Mortality rate within 10 days of birth was less for calves that received colostrum from vaccinated cows, compared with calves that received colostrum from control cows; however, differences were not significant ($P = 0.47$; **Table 1**).

Salmonellae were isolated from 306 of the 309 (99.0%) cows from which 5 or more fecal specimens were collected. The percentage of cows that shed *Salmonella* organisms was similar across groups (Table 1). However, the frequency of fecal shedding differed among groups. Salmonellae were isolated from 648 of 889 (73%), 599 of 841 (71%), and 564 of 895 (63%) fecal swab specimens collected from the control, bacterin, and SC54 groups, respectively. The percentage of specimens from which *Salmonella* spp were isolated was significantly ($P = 0.006$) less for the SC54 group, compared with the other 2 groups. This difference in frequency of shedding reflected a reduction in the shedding of serogroup C1 salmonellae by SC54-vaccinated cows. Group C1 salmonellae were isolated from 448 of 889 (50%), 408 of 841 (48%), and 373 of 895 (41%) fecal swab specimens collected from the control, bacterin, and SC54 groups, respectively. We did not detect significant differences among groups in the percentage of fecal swab specimens that were culture positive for other *Salmonella* serogroups. In addition, no significant differences were observed in fecal shedding of *Salmonella* organisms among cows of different parity.

Twenty-one of the 450 (4.7%) cows enrolled in the study died during the course of the subsequent lactation period. Mortality rate and time from parturition to

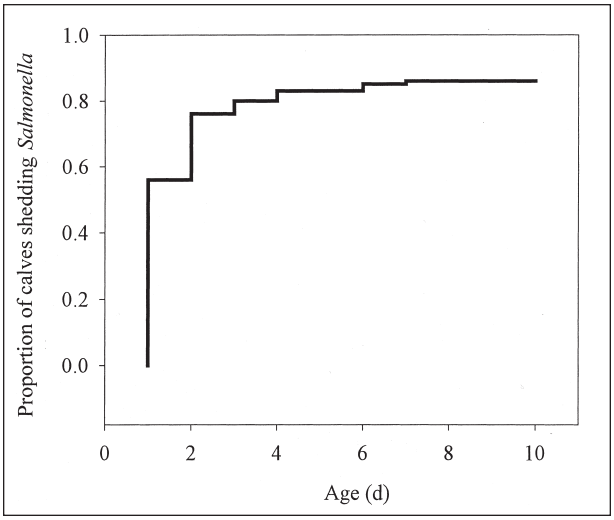

Figure 1—Time from birth to fecal shedding of *Salmonella* organisms by 80 calves.

Table 1—Outcome assessments for nonvaccinated cows (controls), cows vaccinated with a modified live *Salmonella* ser. Choleraesuis strain 54 vaccine (SC54) during late pregnancy, cows vaccinated with a *Salmonella* ser. Montevideo bacterin during late pregnancy, and calves fed colostrum collected from cows in 1 of these groups

	Cows			Calves		
Outcome*	**SC54**	**Bacterin**	**Control**	**SC54**	**Bacterin**	**Control**
Fecal shedding†						
Animals shedding	98.1 (103/105)	99 (99/100)	100 (104/104)	86.2 (25/29)	85.2 (23/27)	88.9 (16/18)
Frequency of shedding‡						
All serogroups	63.0^{ab} (564/895)	71.2^{a} (599/841)	72.9^{b} (648/889)	37.1^{c} (105/283)	54.3^{c} (145/267)	45.7 (79/173)
C1 serogroup	41.7^{a} (373/895)	48.5 (408/841)	50.4^{a} (448/889)	24.7^{a} (70/283)	43.4^{a} (116/267)	38.1 (66/173)
Non C1 serogroups	21.3 (191/895)	22.7 (191/841)	22.5 (200/889)	12.4 (35/283)	10.9 (29/267)	7.5 (13/173)
Longevity						
Mortality§	3.4 (5/148)	6.7 (10/149)	4.2 (6/142)	6.4 (2/31)	12.9 (4/31)	16.6 (3/18)
Culled‖	8.1 (12/148)	6.0 (9/149)	6.3 (9/142)	NA	NA	NA
Production/disease						
Milk	24,066	23,955	24,190	NA	NA	NA
Antimicrobial¶	23.6 (35/148)	23.5 (35/149)	30.3 (43/142)	NA	NA	NA
Mastitis#	27.7 (41/148)	20.8 (31/149)	24.6 (35/142)	NA	NA	NA

*Except for milk production, all data are reported as percentage (No. affected or positive/total No.). Milk production data are reported as mean mature equivalent milk production (lb) during the subsequent lactation period. †*Salmonella* spp isolated from fecal swab specimens collected during the first 10 days after parturition (cows) or birth (calves). ‡Fecal swab specimens that yielded positive results. §Animals that died during the subsequent lactation (cows) or within the first 10 days after birth (calves). ‖Cows culled within 100 days of parturition. ¶Cows treated with antimicrobials during the first 30 days of lactation. #Cows that developed mastitis during the subsequent lactation period.

NA = Not applicable.

$^{a-e}$Values with common superscripts are significantly ($P \leq 0.05$) different.

death were lower in the SC54 group, compared with the other groups, but these differences were not significant ($P = 0.376$). The percentage of cows culled and the time to culling were also similar across groups.

Monthly milk production data were available for 395 of the 450 (87.8%) cows enrolled in the study. Mature equivalent milk production data, calculated by use of DairyComp 305, were used to compare milk production among groups. Mean ME 305 for all cows was 24,072 lb. No significant difference in milk production was observed among groups.

One hundred thirteen of the 439 (26%) cows to calve during the study were treated with antimicrobial drugs during the first 30 days of lactation. The percentage of cows treated with antimicrobial drugs did not differ significantly among groups. Mean number of days of antimicrobial treatment was 2.34. Duration of antimicrobial treatment was similar among groups. One hundred seven (24.3%) cows in the study were reported to have 1 or more episodes of mastitis during the subsequent lactation period, but number of cows with mastitis did not differ among groups.

Mean serum protein concentration in calves was 5.37 mg/dl, and protein concentration did not differ significantly among groups. Salmonellae were isolated from 64 of the 74 (86.5%) calves from which 5 or more fecal swab specimens were collected and from 329 of the 723 (45%) fecal swab specimens collected from calves (Table 1). *Salmonella* organisms were isolated from fecal specimens collected from 43 of 74 (58%) calves at 24 hours of age. Time from birth to fecal shedding of *Salmonella* organisms was similar across groups (**Fig 1**). Percentage of calves that shed *Salmonella* organisms did not significantly differ among groups; however, frequency of shedding did differ. *Salmonella* organisms were isolated from 79 of 173 (46%), 145 of 267 (54%), and 105 of 283 (37%) fecal swab specimens collected from calves that received colostrum from cows in the control, bacterin, and SC54 groups, respectively. Percentage of fecal swab specimens that were culture positive was significantly ($P = 0.045$) less in calves that received colostrum from the SC54 group, compared with calves that received colostrum from the bacterin group, but not in calves that received colostrum from the control group. The difference between groups was associated with a reduction in fecal shedding of serogroup C1 organisms by calves that received colostrum from SC54-vaccinated cows. Serogroup C1 organisms were isolated from 66 of 173 (38%), 116 of 267 (43%), and 70 of 283 (25%) fecal specimens collected from calves that received colostrum from the control, bacterin, and SC54 groups, respectively. We did not detect differences among groups in the percentage of fecal specimens that were culture positive for other *Salmonella* serogroups.

Discussion

At the time this study was initiated, all *Salmonella* vaccines licensed for use in cattle in the United States were bacterins. In 2000, a modified live *S* Dublin vaccine was marketed for use in calves. The reported efficacy of *Salmonella* bacterins ranges from good to ineffective.[7,9,11,17-21] Despite the equivocal results of calf challenge experiments and the lack of documented controlled field trials, *Salmonella* bacterins are commonly administered to dairy cows in the United States. In 1 California survey,[5] 27 of 60 (43%) dairies reported vaccinating cows with a commercial *Salmonella* bacterin. In addition, administration of autogenous *Salmonella* bacterins is common in herds infected with serotypes other than *S* Typhimurium and *S* Dublin. The autogenous *Salmonella* bacterin that we used in the present study was selected because of the high prevalence of *S* Montevideo on this dairy. However, vaccination with this autogenous bacterin had no significant effect on mortality, culling, milk production, or fecal shedding of *Salmonella* organisms by cows during the peripartum period or calves during the first 10 days of life.

Despite frequent fecal shedding of salmonellae by cows and calves in this herd, clinical signs of salmonellosis were not observed in either group during the 3 months prior to the study. During the course of the study, approximately 50 cows developed clinical signs of salmonellosis. The increased rate of *Salmonella* shedding and the development of clinical disease in some cows corresponded to high environmental temperatures and summer rainfall. Presumably, the heat and humidity stressed the cows and decreased innate immunity.

The high prevalence of fecal shedding of *Salmonella* organisms observed during the study was particularly striking, considering swabs were used to collect feces for *Salmonella* isolation. Use of fecal swab specimens for *Salmonella* culture is less sensitive than use of larger volumes of fecal specimens. However, because our study design called for the collection and processing of 5,300 fecal specimens over 56 days, swabs were selected to expedite the process. The limit of detection is approximately 50 and 90% for swab specimens of feces containing 10 to 999 and 1,000 to 100,000 *Salmonella* organisms/g, respectively.[22] Thus, we assumed that the actual prevalence of fecal shedding in the present study was even higher than that detected.

A number of naturally occurring and genetically manipulated attenuated *Salmonella* strains have been used to immunize cattle against salmonellosis. Results of comparative vaccine trials indicate modified live attenuated *Salmonella* vaccines provide greater protection against challenge with virulent *Salmonella* strains than do *Salmonella* bacterins.[9-12] In addition, results of a number of studies[23-25] suggest that some modified live *Salmonella* vaccines provide protective immunity against challenge with heterologous serotypes. The serogroup C1 *S* Choleraesuis vaccine used in the present study was reported to protect calves from challenge with *S* Dublin (serogroup D1).[15] In that study, calves vaccinated at 5 to 7 weeks of age shed fewer *Salmonella* organisms and remained healthier following challenge with *S* Dublin at 7 to 9 weeks of age, compared with nonvaccinated calves. Similar results have been obtained with other modified live *Salmonella* vaccines[23-25]; in those studies, immunized calves were protected from challenge with homologous and heterologous serotypes within 3 weeks of vaccination. It is not clear whether the protection afforded is

attributable to immunologic memory or a transitory T-cell independent nonspecific protection that typically lasts approximately 1 month after immunization with modified live *Salmonella* vaccines.[26] Most modified live *Salmonella* vaccines persist in the host for 7 to 21 days. T-Cell dependent immunologic memory attributable to administration of a modified live *Salmonella* vaccine can only be evaluated after allowing at least a 4-week interval between clearance of the vaccine and experimental challenge. In the present study, fewer cows vaccinated with the modified live *S* Choleraesuis strain 54 vaccine shed C1 organisms in feces than either the unvaccinated controls or cows vaccinated with the autogenous bacterin. In addition, calves that received colostrum from cows vaccinated with the modified live vaccine also shed serogroup C1 organisms less frequently than calves that received colostrum from cows vaccinated with the *Salmonella* bacterin. Neither vaccine, however, had any effect on shedding of heterologous serogroups. The apparent discrepancy between results of this study and the previous study[15] in which the modified live *S* Choleraesuis (serogroup C1) vaccine reduced shedding of *S* Dublin (serogroup D1) organisms may reflect the increased interval from vaccination to outcome assessment in the present study. Outcome assessment in this study evaluated the effects of T-cell dependent immunologic memory.

The brief interval from birth to detection of *Salmonella* organisms in feces of calves was striking; 43 of 74 (58%) calves shed *Salmonella* organisms within 24 hours of birth. Considering the early age at which calves are exposed to *Salmonella* organisms, it is not surprising that *Salmonella* bacterins are ineffective when administered to this age group. The decreased frequency of fecal shedding of serogroup C1 *Salmonella* organisms by calves that received colostrum from SC54-vaccinated cows indicated that calves were, at least in part, passively protected by ingestion of colostrum from vaccinated cows. In other species, administration of modified live *Salmonella* vaccines to neonates at birth reduces colonization by virulent strains of *Salmonella*.[27] Further testing of the SC54 vaccine in neonatal calves is needed to evaluate competitive exclusion induced by this vaccine and its capacity to induce active neonatal immunity under field conditions.

In the present study, the efficacy of 2 *Salmonella* vaccines was evaluated on a farm endemically infected with *Salmonella* spp. Conditions on this dairy were typical of large commercial dry lot dairies and reflected the common field application of *Salmonella* vaccines in dairy cattle. Animal health and welfare and production and food safety issues provide impetus for dairy owners to vaccinate cattle against salmonellosis. On this dairy, *S* Montevideo was the predominant serotype isolated from feces of cows. *Salmonella* Montevideo belongs to serogroup C1. In this controlled field study, administration of a commercial modified live *S* Choleraesuis swine vaccine to pregnant cows resulted in a reduction of fecal shedding of serogroup C1 organisms by vaccinated cows and by calves fed colostrum from these cows. In both cows and calves, the reduction in fecal shedding of serogroup C1 organisms was approximately 25%, compared with bacterin-vaccinated and nonvaccinated animals. Despite the reduction in shedding of *Salmonella* organisms, no differences were detected in milk production, culling, or mortality rates among groups. The capacity of the commercial modified live *S* Choleraesuis swine vaccine to reduce fecal shedding of *Salmonella* organisms by vaccinated cows suggests that it is also capable of inducing some degree of protection against infection in cattle. To our knowledge, this is the only *Salmonella* vaccine in the United States that has a demonstrated efficacy against infections with serogroup C1 salmonellae in cattle.

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[a]Alhydrogel 1.3%, Superfos Biosector a/s Bøgeskovvej 7, Kvistgard, Denmark.

[b]Quill A, Accurate Chemicals, Westbury, NY.

[c]SC-54, NOBL Laboratories Inc, Sioux Center, Iowa.

[d]Triple Sugar Iron, Media Services, University of California, Davis, Calif.

[e]Urea, Media Services, University of California, Davis, Calif.

[f]O-nitrophenyl-β-D-galactopyranoside, Media Services, University of California, Davis, Calif.

[g]*Salmonella* antisera, Difco, BD Diagnostic Systems, Sparks, Md.

[h]Department of Agriculture Animal and Plant Health Inspection Service National Veterinary Services Laboratories, Ames, Iowa.

References

1. Donnelly CW. Concerns of microbial pathogens in association with dairy foods. *J Dairy Sci* 1990;73:1656–1661.

2. Centers for Disease Control. Outbreaks of *Salmonella enteritidis* gastroenteritis—California. *MMWR Morb Mortal Wkly Rep* 1993;42:41.

3. Pacer R, Thurmond M, Ryan C, et al. *Salmonella newport* in cattle: an animal and human health problem, in *Proceedings*. 80th Annu Meet U S Anim Health Assoc 1986;374–380.

4. Pacer RE, Spika JS, Thurmond MC, et al. Prevalence of *Salmonella* and multiple antimicrobial-resistant *Salmonella* in California dairies. *J Am Vet Med Assoc* 1989;195:59–63.

5. Smith BP, Da Roden L, Thurmond MC, et al. Prevalence of salmonellae in cattle and in the environment on California dairies. *J Am Vet Med Assoc* 1994;205:467–471.

6. Kabagambe EK, Wells SJ, Garber LP, et al. Risk factors for fecal shedding of *Salmonella* in 91 US dairy herds in 1996. *Prev Vet Med* 2000;43:177–194.

7. Smith BP, Habasha FG, Reina-Guierra M, et al. Immunization of calves against salmonellosis. *Am J Vet Res* 1980;41: 1947–1951.

8. Aitken MM, Jones PW, Hall GA, et al. Responses of fluke-infected and fluke-free cattle to experimental reinfection with *Salmonella dublin*. *Res Vet Sci* 1981;31:120–126.

9. Robertsson JA, Lindberg AA, Hoiseth S, et al. *Salmonella typhimurium* infection in calves: protection and survival of virulent challenge bacteria after immunization with live or inactivated vaccines. *Infect Immun* 1983;41:742–750.

10. Smith HW. The immunization of mice, calves, and pigs against *Salmonella dublin* and *Salmonella cholerae-suis* infections. *J Hyg* 1965;63:117–135.

11. Cameron CM, Fuls W. Immunization of mice and calves against *Salmonella dublin* with attenuated live and inactivated vaccines. *Onderstepoort J Vet Res* 1976;43:31–37.

12. Baljer G, Hoerstke M, Dirksen G, et al. Comparative studies of the effectivity of oral immunization with heat-inactivated and live, avirulent (Gal E) *S. typhimurium* bacteria against salmonellosis in calves. *Zentralbl Veterinarmed [B]* 1981;28:759–766.

13. Hunter AG, Peek IS. Vaccination control of an outbreak of *Salmonella typhimurium* infection in suckler cows and calves. *Br Vet J* 1977;133:239–244.

14. Smith BP, Dilling GW, House JK, et al. Enzyme-linked immunosorbent assay for salmonella serology using lipopolysaccharide antigen. *J Vet Diagn Invest* 1995;7:481–487.

15. Fox BC, Roof MB, Carter DP, et al. Safety and efficacy of an

avirulent live *Salmonella choleraesuis* vaccine for protection of calves against *S dublin* infection. *Am J Vet Res* 1997;58:265–271.

16. Roof MB, Kramer TT, Roth JA, et al. Characterization of a *Salmonella choleraesuis* isolate after repeated neutrophil exposure. *Am J Vet Res* 1992;53:1328–1332.

17. Steinbach G, Meyer H. Efficacy of subcutaneous inoculation of calves with "Murivac" inactivated salmonellosis vaccine. *Tierarztl Prax* 1994;22:529–531.

18. Bairey MH. Immunization of calves against salmonellosis. *J Am Vet Med Assoc* 1978;173:610–613.

19. Aitken MM. Salmonellosis—chemotherapy or vaccination. *Ir Vet News* 1986;18:3–8.

20. Aitken MM, Jones PW, Brown GTH. Protection of cattle against experimentally induced salmonellosis by intradermal injection of heat-killed *Salmonella dublin*. *Res Vet Sci* 1982;32:368–373.

21. Baljer G, Hoerstke M, Dirksen G, et al. Efficacy of a local and/or parenteral immunization against salmonellosis in calves with inactivated vaccines. *Zentralbl Veterinarmed [B]*1986;33:206–212.

22. McCall CE, Martin WT, Boring JR. Efficiency of cultures of rectal swabs and faecal specimens in detecting salmonella carriers: correlation with numbers of salmonellas excreted. *J Hyg* 1966; 64:261–269.

23. Rankin JD, Newman G, Taylor RJ. The protection of calves against infection with *Salmonella typhimurium* by means of *Salmonella dublin* (strain 51) vaccine. *Vet Rec* 1966;78:765–766.

24. Smith BP, Reina-Guerra M, Stocker BA, et al. Aromatic-dependent *Salmonella dublin* as a parenteral modified live vaccine for calves. *Am J Vet Res* 1984;45:2231–2235.

25. Wray C, Sojka WJ, Morris JA, et al. The immunization of mice and calves with gal E mutants of *Salmonella typhimurium*. *J Hyg* 1977;79:17–24.

26. Angerman CR, Eisenstein TK. Correlation of the duration and magnitude of protection against Salmonella infection afforded by various vaccines with antibody titers. *Infect Immun* 1980;27: 435–443.

27. Methner U, Barrow PA, Martin G, et al. Comparative study of the protective effect against Salmonella colonisation in newly hatched SPF chickens using live, attenuated Salmonella vaccine strains, wild-type Salmonella strains or a competitive exclusion product. *Int J Food Microbiol* 1997;35:223–230.

Correction: Use of sample size for estimating efficacy of a vaccine against an infectious disease

In the article "Use of sample size for estimating efficacy of a vaccine against an infectious disease" (*AJVR*, Oct 2001, pp 1582–1584), the equations on page 1582 for the calculation of vaccine efficacy (VE) are incorrect. The correct equations are as follows:

$$VE = \frac{IP_{nv} - IP_{v}}{IP_{nv}} \times 100\%, \text{ or}$$

$$VE = \frac{0.4 - 0.2}{0.4} \times 100\% = 50\%$$