Fluorescence Polarization Assay for Detection of *Brucella abortus* Antibodies in Bulk Tank Bovine Milk Samples

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Received 14 December 2001/Returned for modification 12 June 2002/Accepted 9 August 2002

A simple, rapid, inexpensive fluorescence polarization assay for the detection of antibodies to *Brucella abortus* in bulk tank milk samples at the farm level or at dairies with a sensitivity and specificity of 100 and 95.9%, respectively, is described. The assay detects antibodies to *B. abortus* in 15 min by testing undiluted whey produced by chemical and physical manipulation of milk from bulk tanks. This sampling is noninvasive and therefore costs less and is less stressful than blood-based tests. The assay is specific and can detect antibodies at levels below that of the indirect enzyme immunoassay for milk and the fluorescence polarization assay for individual milk samples. Use of this assay would make programs for surveillance of dairy animals and eradication of *B. abortus* more cost-effective.

The presence of *Brucella abortus* bacterial infection in milk was reported by Schroeder (E. C. Schroeder, E. S. R. 27:281, 1912) in 1912, and the presence of agglutinins in the milk of infected animals was reported by Cooledge (L. H. Cooledge, J. Agr. Res. 5:871, 1916). A laboratory test for the diagnosis of bovine brucellosis using milk samples was not attempted until 1937, when the milk ring test (MRT) was developed by Fleischhauer (G. Fleischhauer, Berl. Tierarzt. Wochenschr. 53:527-528, 1937). At the time, this test was considered highly sensitive (G. Fleischhauer and G. Hermann, Berl. Tierarztl. Wochenschr. 54:333, 1938) due to its ability to detect antibodies in milk from one infected animal mixed with milk from 5 to 10 cows negative for this pathogen. However, there were many shortcomings, including false-positive reactions associated with the MRT, as listed in Table 1. Nicoletti (10) showed that the MRT correctly identified 88.5% of animals in which *MRT*, as listed in Table 1. Nicoletti (10) showed that the MRT shortcomings, including false-positive reactions associated with the MRT, as listed in Table 1. Nicoletti (10) showed that the MRT correctly identified 88.5% of animals in which *MRT*, as listed in Table 1. Nicoletti (10) showed that the MRT working with milk samples from herds of 100 or more cattle (2, 6, 13). In the preparation of reagents, all chemicals were from Sigma-Aldrich Chemical Company, St. Louis, Mo. A trizma base reagent grade was used in the preparation of 0.04 M TRIS buffer with 0.01 M EDTA. Both were dissolved in pyrogen-reduced 18-MΩ water. The pH was adjusted to 10.2 with 0.06 M NaOH. A 1.0 M sodium dithionite (sodium hydrosulfite) solution was prepared in 0.04 M Tris-0.01 M EDTA buffer and allowed to equilibrate overnight before the preparation of a 0.25 M solution diluted in 0.04 M Tris-0.01 M EDTA buffer. Aliquots of the 0.25 M solution (0.5 ml) were dispensed into borosilicate glass
Decolorization induced by bacterial growth after long incubation periods could affect the strength of the reaction and subsequent interpretation. 

The MRT was subject to nonspecific reactions caused by testing colostrum or milk from cows with mastitis. 

In addition to the subjective nature of the test it was also recognized that results were dependent on the ability of laboratory personnel to read the test correctly. 

It was known that antibodies against cross-reacting organisms would produce reactions in the MRT resulting in false positives. 

MRT depends on the presence of cream, making the test difficult to perform. The cream content varies with individual animals and would be diluted with pooled or bulk tank samples. 

Partial freezing of negative milk could result in weak nonspecific reactions. 

Animals vaccinated as calves produced weak reactions upon maturity. 

<table>
<thead>
<tr>
<th>TABLE 1. Problems associated with the milk ring test</th>
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<tr>
<td>Description</td>
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| Milk treatment and bmFPA. Before testing, 2-ml milk controls and test samples were treated with 10 μl of 1-g/ml of citric acid, resulting in the precipitation of casein after approximately 10 repeated inversions. Subsequently, the milk samples were mixed using a vortex for 3 min at maximum speed to congeal the fat in the milk sample. The resultant skim milk sample (1.8 ml) was dispensed into 2-ml microcentrifuge tubes and centrifuged at ±5,600 × g using a portable microcentrifuge for approximately 6 min per sample. After centrifugation, 1 ml of the whey was removed with a pipette from the supernatant and dispensed into a borosilicate glass tube containing lyophilized sodium dithionite. After through mixing (5 s) on a vortex to ensure a homogeneous mixture of the whey sample, a blank measurement was obtained using a portable fluorescence polarization analyzer (Sentry FP; Diachemin Corporation, Grayslake, Ill.). A predetermined amount (10 μl) of B. abortus O-polysaccharide conjugated with fluorescein isothiocyanate (14) was added and thoroughly mixed for 5 s. After incubation at room temperature for at least 2 min, a second measurement was determined with the blank subtracted. Data from this assay were expressed as mP. 

Using statistical software (17), upper control limits (UCL) and lower control limits (LCL) (±3 standard deviations [SD]) were obtained for the positive and negative controls. With the same software, using previously defined negative (n = 219) and positive (n = 39) milk samples, the sensitivity, specificity, and an associated cutoff were determined using receiver operating characteristics. |

RESULTS

UCL and LCL of the positive and negative controls ±3 SD from the mean (18) for the bmFPA were determined by testing each control over a 6-month period for a total of 43 observations. For the positive control the UCL and LCL were 339.42 and 223.72 mP, respectively (Fig. 1). Similarly, the UCL and LCL for the negative control were 137.55 and 79.71 mP, respectively (Fig. 1). The running average for positive and negative controls were 281.57 and 108.62 mP, respectively (dashed lines in Fig. 1). No control data exceeded the UCL and LCL and rarely exceeded ±2 SD as shown in Fig. 1. The percent coefficient of variation (%CV) of the positive control was 6.85%, while the %CV of the negative control was 8.87%.

Using the calculated negative cutoff of 140 mP, a detection limit of one infected animal in approximately 2,000 negative animals ±2 SD was estimated, as presented in Fig. 2, where dilutions on the x axis represent postulated herd sizes. The %CVs at a 1:1,600 dilution and a 1:3,200 dilution were 9.8 and 14.4%, respectively. 

The sensitivity, specificity, and cutoff of the bmFPA were determined using receiver operating characteristics analysis based on a B. abortus-negative population of 219 samples and a B. abortus-positive population of 39 samples. The sensitivity and specificity with 95% confidence limits (CL) of the bmFPA (negative cutoff < 140 mP) were 100% (95% CL, 88.2 to 100 mP) and 95.9% (95% CL, 92.1 to 98.0 mP), respectively, as presented in Table 2. Similarly, the sensitivity and specificity of the mELISA were 76.9 and 100%, respectively, while the sensitivity and specificity of the mELISA were 94.9 and 91.8%, respectively.

Presented in Table 3 are the positive and negative predictive values of the bmFPA (cutoff, 140 mP) for disease prevalences of 0.01, 0.1, 1, 10, 15, and 20% and a sensitivity and specificity of 100 and 95.9%, respectively. As the disease prevalence increases, the positive predictive value (PPV) increases while the negative predictive value (NPV) remains unchanged. A PPV is the probability the disease being present when the test is positive and an NPV is the probability the disease is not present when the test is negative.

DISCUSSION

The development of a simple, rapid, inexpensive FP assay with excellent accuracy suitable for testing bulk tank milk sam-

The indirect enzyme immunoassay for milk (mELISA) was done as described by Nielsen et al. (15). Briefly, the milk was diluted 1:25 in 0.01 M Tris buffer containing 0.15 M NaCl, 10 mM EDTA, and 0.05% Igepal CA630 and was mixed. After mixing, a blank reading was obtained using the portable fluorescence polarization analyzer, and this was followed by the addition of appropriately diluted O-polysaccharide conjugated with fluorescein isothiocyanate; the solution was mixed and equilibrated for 2 min. After equilibration, a reading was obtained. Results were expressed in mP units. In the absence of anti-Brucella antibodies (negative milk) the result was low mP values; high mP values resulted from the presence of Brucella specific antibodies (positive milk).
samples at the farm level or dairy level would be a desirable addition to diagnostic tests for controlling bovine brucellosis.

The bmFPA is a simple, cost-effective, rapid (less than 15 min), inexpensive assay developed for testing bulk tank milk samples. The noninvasive sampling procedure would result in further reductions in the costs of blood collection material and labor and stress-related symptoms in cattle, such as reduced milk production. It would be particularly useful in individual dairy herds with high prevalence of brucellosis, where samples reacting on the bmFPA would most likely have antibody to *B. abortus* infection. At a prevalence of 20%, the positive predictive value was 85.9% (Table 3). This indicates that more than 8 out of every 10 samples testing positive by the bmFPA could have antibody to *B. abortus* infection. Because of the high NPVs (Table 3), samples testing negative by the bmFPA would mostly likely not be *B. abortus* infected.

![Standard quality control charts with UCL and LCL set at 3 SD for the positive and negative controls. The running average is depicted as a dashed line. The x axis shows the number of observations, while the y axis is in mP units.](http://cvi.asm.org/)

![Mean (n = 10 repeat titrations) titration curve ±2 SD of a *B. abortus*-positive milk sample artificially constructed to simulate one infected animal in a bulk milk tank for herds of various sizes. Values plotted along the x axis are the dilutions representing the hypothetical herd sizes, while those plotted along the y axis are in mP units.](http://cvi.asm.org/)

FIG. 1. Standard quality control charts with UCL and LCL set at 3 SD for the positive and negative controls. The running average is depicted as a dashed line. The *x* axis shows the number of observations, while the *y* axis is in mP units.

FIG. 2. Mean (*n* = 10 repeat titrations) titration curve ±2 SD of a *B. abortus*-positive milk sample artificially constructed to simulate one infected animal in a bulk milk tank for herds of various sizes. Values plotted along the *x* axis are the dilutions representing the hypothetical herd sizes, while those plotted along the *y* axis are in mP units.
These and other organisms are capable of evoking low levels of antibody in samples that were negative for *B. abortus* by the mFPA and the mELISA. Riboflavin (vitamin B<sub>2</sub>) also imparts a greenish color (optical properties as reported by the Dairy Science and Technology of the University of Guelph [http://www.foodsci.uoguelph.ca/dairyedu/chem.html]) to the whey, again probably due riboflavin fluorescence. Without sodium dithionite, the capacity of the photo multiplier tube of the FPA reader was easily overwhelmed (see Sentry FP operator manual [Diachemix Corporation] and FPM-1 fluorescence polarization analyzer operator manual, revision 2.0 [Jolley Consulting and Research, Inc., Grayslake, Ill.]), resulting in negative polarization values, negative intensity values, and erroneous millipolarization results. Addition of sodium dithionite allowed antibody in the whey to be measured undiluted, compared with the mFPA which was performed at a 1.25 dilutions.

The bmFPA demonstrated the best sensitivity (Table 2) compared with the mFPA and the mELISA. Since the milk samples were not diluted, the sensitivity of the bmFPA (100%) exceeded the sensitivities of the mFPA (76.9%) and the mELISA (94.9%). Low antibody levels produced from cross-reacting organisms (8) such as *Escherichia coli* 0:116, *Salmonella enterica* serovar Urbana 0:30, and *Pseudomonas maltophilus* strain 555 would not be diluted out in the bmFPA, which may explain the lower specificity (95.9%) of the bmFPA compared with the mFPA (100%), in which the milk was diluted 1:25. These and other organisms are capable of evoking low levels of antibodies reacting with *Brucella* antigens (8). Autofluorescence of milk components other than riboflavin could cause false-positive reactions, resulting in the lower specificity. Interference from lipids in the fresh milk samples could trap the enzyme conjugate used in the mELISA, resulting in a lower specificity (91.8%) of this test.

The quality control data presented in Fig. 1 demonstrate remarkably low day-to-day and test-to-test variation for the bmFPA, and the bmFPA compares favorably with the ELISA formats, where coefficients of variation of <20% among negatives were considered good. The bmFPA displayed good quality control over a 6-month period involving different batches of reagents, buffer, and controls. The control data never exceeded the UCL and LCL. Control samples were simple and inexpensive to prepare in-house, which would simplify their production locally and for international standardization.

The detection limit of this assay was determined by using 10 repeat titrations of an artificially constructed positive sample as presented in Fig. 2. Using the cutoff of 140 mP, the bmFPA in theory could detect one animal with *B. abortus* antibodies milk in more than 2,000 animals negative for *B. abortus*, which exceeded the mELISA (one infected animal in 100 animals) and the MRT (one infected animal in 5 or 10 animals) using similar methodology (2, 6, 13; Fleischhauer and Hermann, Berl. Tierarztl. Wochenschr. 54:333, 1938). The average dairy herd size in Canada is approximately 48 animals; therefore, a test that can detect one *B. abortus*-positive animal in 2,000 *B. abortus*-negative animals would be ideal for noninvasive screening for the detection of antibodies to *B. abortus* in milk. Analogously, a bulk tank with a capacity of 1,150 liters is sufficient to hold milk from 40 dairy cows producing on average 29 liters of milk per day, again making this test ideal for noninvasive screening. Because milk samples are not diluted in the bmFPA, animals at early stages of infection may be detected sooner with this test than with the mFPA that requires samples to be diluted 1:25 possibly diluting samples with low antibody levels to extinction.

Twenty-three milk samples banked from animals from which *B. abortus* had been isolated were used in this study. It was apparent from the data in this study that antibody activity in the stored milk samples could still be detected after 20 years of storage (samples were collected in 1981 and 1982). In all these samples the casein and total milk solids had precipitated. Treatment of these samples was the same as that of the freshly collected samples. An equal number of banked samples were not useable due to an irreversible aggregation phenomenon known as age gelation caused by aggregation of the micelles into long chains forming a three-dimensional network (http://www.foodsci.uoguelph.ca/dairyedu/chem.html).

Further studies are required to evaluate and validate the bmFPA for field use; however, this study showed that the bmFPA was a simple, rapid, and inexpensive test that compared favorably with traditionally used tests (mELISA) for detection of milk antibodies to *B. abortus*. The assay would be useful in surveillance and eradication programs, reducing costs significantly. Evaluation of this method for the detection antibodies to *B. melitensis* in milk from small ruminants should be considered, as the MRT works poorly with milk from sheep and goats (1).

**TABLE 2. Sensitivities and specificities of various tests**

<table>
<thead>
<tr>
<th>Test (cutoff)</th>
<th>% Sensitivity (95% CL)</th>
<th>% Specificity (95% CL)</th>
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<tbody>
<tr>
<td>bmFPA (140 mP)</td>
<td>100 (88.8–99.8)</td>
<td>95.9 (92.1–98.0)</td>
</tr>
<tr>
<td>mFPA (87 mP)</td>
<td>76.9 (60.2–88.3)</td>
<td>100 (97.8–99.9)</td>
</tr>
<tr>
<td>mELISA (20% P)</td>
<td>94.9 (81.4–99.1)</td>
<td>91.8 (87.1–94.9)</td>
</tr>
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</table>

**TABLE 3. Predictive values of bmFPA**

<table>
<thead>
<tr>
<th>Prevalence</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.2</td>
<td>100</td>
</tr>
<tr>
<td>0.10</td>
<td>2.4</td>
<td>100</td>
</tr>
<tr>
<td>1.00</td>
<td>19.8</td>
<td>100</td>
</tr>
<tr>
<td>10.0</td>
<td>73</td>
<td>100</td>
</tr>
<tr>
<td>15.0</td>
<td>81.1</td>
<td>100</td>
</tr>
<tr>
<td>20.0</td>
<td>85.9</td>
<td>100</td>
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* Comparison of PPVs and NPVs of the bmFPA (negative cutoff = 140 mP) with a test sensitivity and specificity of 100 and 95.9%, respectively.

ACKNOWLEDGMENTS

We thank the Dairy Farmers of Ontario (Jeff Hyndman and George MacNaughton) for their assistance in obtaining bulk tank samples.

**REFERENCES**