Antibody Responses of Cattle with Respiratory Coronavirus Infections during Pathogenesis of Shipping Fever Pneumonia Are Lower with Antigens of Enteric Strains than with Those of a Respiratory Strain

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The role of coronaviruses as respiratory pathogens in cattle was recently recognized when numerous coronavirus strains were isolated from the nasal secretions and lung tissues from cattle with fatal cases of shipping fever pneumonia (SFP). These isolates are referred to as respiratory bovine coronaviruses (RBCV) (18, 19). The enteropathogenic potential of coronaviruses was identified previously when these viruses were isolated from diarrhea fluid or intestinal samples from neonatal calves with severe diarrhea (7, 13). In addition, coronaviruses were implicated in winter dysentery of adult cattle (14). These coronaviruses are referred to as enteropathogenic bovine coronaviruses (EBCV). Significant phenotypic, antigenic, and genetic differences separate the newly recognized RBCV from EBCV (2, 3, 11, 18). Furthermore, infectivity-neutralizing (IN) and hemagglutinin-inhibiting (HAI) activities were tested. Sequential serum samples, collected during the onset of the respiratory coronavirus infection and at weekly intervals for 5 weeks thereafter, had significantly higher IN and HAI titers for antigens of RBCV strain 97TXSF-Lu15-2 than for the wild-type and the highly cell culture-adapted EBCV strains, with P values ranging from <0.0001 to 0.0483. The IN and HAI antibody responses against the two EBCV strains did not differ significantly, but the lowest titers were detected with EBCV strain L9-81.

The serum antibody responses of cattle with respiratory coronavirus infections during the pathogenesis of shipping fever pneumonia were analyzed with different bovine coronavirus antigens, including those from a wild-type respiratory bovine coronavirus (RBCV) strain (97TXSF-Lu 15-2) directly isolated from lung tissue from a fatally infected bovine, a wild-type enteropathogenic bovine coronavirus (EBCV) strain (Ly 138-3), and the highly cell culture-adapted, enteric prototype strain (EBCV L9-81). Infectivity-neutralizing (IN) and hemagglutinin-inhibiting (HAI) activities were tested. Sequential serum samples, collected during the onset of the respiratory coronavirus infection and at weekly intervals for 5 weeks thereafter, had significantly higher IN and HAI titers for antigens of RBCV strain 97TXSF-Lu15-2 than for the wild-type and the highly cell culture-adapted EBCV strains, with P values ranging from <0.0001 to 0.0483. The IN and HAI antibody responses against the two EBCV strains did not differ significantly, but the lowest titers were detected with EBCV strain L9-81.

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agitation (19). The wild-type RBCV strain 97TXSF-Lu15-2 was used at its second passage in clone G cells after initial isolation from lung tissue of a calf that died on day 8 of the epizootic (18). The highly cell culture-adapted EBCV strain L9-81 was originally isolated from bovine fetal kidney cell cultures as the EBCV Mebus strain (10, 13, 14). The EBCV L9-81 strain was propagated in 75 sequential passages in different bovine cell cultures, and the final six passages were done in clone G cells. The virulent wild-type EBCV strain LY138-3 from intestinal passage in clone G cells after initial isolation from lung tissue from a calf that died on day 8 of the epizootic (18). The highly cell culture-adapted EBCV strain L9-81 was originally isolated from bovine fetal kidney cell cultures as the EBCV strain L9-81. The kinetics of the responses in HAI antibodies against RBCV strain 97TXSF-Lu15-2 (circles), EBCV strain L9-81 (triangles), and EBCV strain LY138-3 (squares) in serum samples from cattle. Cattle in response group 1 (A and C) shed RBCV on day 7 and had clinical signs of respiratory tract disease, while cattle in response group 5 (B and D) did not develop adverse clinical signs and remained virus isolation negative, despite exposure to the animals that were shedding virus (response group 1). Data are means ± standard errors of the means (error bars). Results are shown for seven cattle (A and C) and for seven cattle (B and D).

Comparison of HAI activities of serial serum samples with antigens of RBCV strain 97TXSF-Lu15-2 and EBCV strains L9-81 and LY138-3. The kinetics of the responses in HAI antibodies against RBCV strain 97TXSF-Lu15-2 were significantly greater than those against EBCV strain L9-81, with P values of 0.0001 and 0.0001 for the results for cattle of response groups 1 and 5, respectively. The differences between RBCV strain 97TXSF-Lu15-2 and EBCV strain LY138-3 were significant at a P value of 0.0001 for both groups 1 and 5 (Fig. 1C and D). The HAI activities against RBCV strain 97TXSF-Lu15-2 and EBCV strain L9-81 were remarkably different in serum samples collected from cattle in response group 1 for days 7, 14, 21, 28, and 35, respectively, with P values of 0.0483, 0.0004, 0.0035, <0.0001, <0.0001, and <0.0001. The HAI activities showed similar differences among cattle in response group 5 from day 0 onward with a P value of <0.0001. Levels of HAI antibodies against RBCV strain 97TXSF-Lu15-2 and EBCV strain LY138-3 were also substantially different for the cattle in response group 1 for days 7, 14, 21, 28, and 35 (P values of 0.0035; 0.0483; <0.0001, 0.0001, and <0.0001, respectively), and for the cattle in response group 5 for days 0, 7, 14, 21, 28, and 35 (P values of 0.0024, <0.0001, <0.0001, <0.0001, and <0.0001, respectively). Significant differences between serum HAI antibody kinetics against EBCV strain
L9-81 and EBCV strain LY138-3 were not observed in cattle of either response group.

**DISCUSSION**

Prospectively designed and experimentally controlled sampling and testing of cattle during a naturally occurring SFP epizootic created fortuitous circumstances for analyzing the kinetics of antibody responses of cattle to a native, wild-type RBCV infection (18, 19). This experiment also provided an excellent opportunity to compare antibody reactivities with both the wild-type RBCV and the highly cell-culture-adapted and wild-type EBCV strains in serum samples collected from cattle involved in a naturally occurring RBCV infection. These conditions differ from experimentally induced infections that routinely involve giving virus inocula adapted to, and propagated in, cell cultures. Importantly, the IN and HAI antibody responses against RBCV were significantly greater than those detected with the wild-type EBCV strain LY138-3 and the highly cell culture-adapted EBCV. The EBCV strain L9-81 is virtually identical to the Norden vaccine strain that is used in attempts to protect against intestinal coronavirus infections of neonatal calves. Antigens of the highly cell culture-adapted EBCV strains reacted minimally with antibodies induced by naturally occurring RBCV infections. These findings call for analysis and a search for appropriate antigens in efforts to immunize cattle against these currently prevailing RBCV infections.

Bovine coronaviruses contain a large, single-stranded RNA genome and may mutate in the natural host to generate quasispecies differences (2, 3). Phenotypic changes may result from adaptation to, and propagation of, the virus in cell cultures, effecting the selection of host cell virus mutants. Differences in infectivity between the highly cell-culture-adapted EBCV strain L9-81 and the wild-type strains of RBCV and EBCV consisted of a greatly expanded range of permissive host cells. This EBCV strain replicates readily, particularly in the presence of trypsin and in cultured bovine fetal kidney, spleen, thyroid, or adrenal cells, as well as in Vero cells (23). In contrast, the wild-type RBCV strains had restricted host cell ranges, because only clone G cells were permissive for initial isolation from clinical samples at low passage levels (18, 19, 23).

Differences between the RBCV and EBCV strains also were observed in the HA patterns, cell fusion, and AE activities (11, 19). Antigenic differences between RBCV and EBCV could not be detected by tests such as immunodiffusion immunofluorescence, immunoblotting, or enzyme-linked immunosorbent assays with antigens that include all the structural proteins of these coronaviruses (10, 12, 21, 22). MAb specific for S glycoprotein with IN activity distinguished between EBCV strain L9-81 and several wild-type strains of EBCV (8). Differences between EBCV strain L9-81 and the wild type strain LY138-3 of EBCV in inhibition of AE activity with HE-specific MAb (25) and in HA (4) reactivities were also detected.

Genotypic differences consisted of changes in the regions of the polymerase and associated genes, in the genes of S and HE glycoproteins, and in other nonstructural genes (2, 3, 11). Nucleotide and deduced amino acid mutations were within the A and B immunoreactive domains of the S-I subunit of the spike protein of the RBCV strains but not the EBCV strains, which could be the basis for the observed diversity in antigenic stimulation during these naturally occurring infections (2).

Comparatively, the differences in the kinetics of the primary bovine antibody responses to naturally occurring and experimentally monitored RBCV infections with the antigens of the wild-type RBCV and EBCV strains as well as the highly cell culture-adapted EBCV appear to be similar to responses of chickens to infections with the coronavirus of infectious bronchitis. Early antibodies generated during a primary immune response distinguished several serotypes of infectious bronchitis in both IN and HAI tests (1, 9).

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