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FOOT-AND-MOUTH DISEASE IN NORTH AMERICAN BISON (*BISON BISON*) AND ELK (*CERVUS ELAPHUS NELSONI*): SUSCEPTIBILITY, INTRA- AND INTERSPECIES TRANSMISSION, CLINICAL SIGNS, AND LESIONS

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ABSTRACT: There is limited information about the pathogenesis and epidemiology of foot-and-mouth disease (FMD) in North American bison (*Bison bison*) or elk (*Cervus elaphus nelsoni*). In these two experimental infection studies, we compared the susceptibilities of bison and elk to FMD virus (FMDV), respectively, with that of cattle; determined whether intra- and interspecies transmission could occur in bison and cattle, and elk and cattle; determined suitability of conventional available laboratory tests to detect FMDV infection in bison and elk; and investigated whether bison or elk are efficient long-term carriers of FMDV. In both studies, after a period of acclimation to the containment at Plum Island Animal Disease Center, animals were infected by intraepithelial tongue inoculation with 10,000 bovine tongue infective doses of FMDV, strain O1 Manisa. Inoculated animals were kept with contact animals; subsequently, inoculated and/or exposed contact animals were placed in rooms with unexposed animals. All bison developed oral mucosal and foot lesions similar to those of cattle. Bison developed fever, lameness, inappetence, and ptyalism. Physical examinations on bison revealed numerous small vesicles and erosions affecting tongue, gingiva, muzzle, hard and soft palates, coronary bands, and interdigital skin. Inoculated elk developed transient fever and mild focal tongue and foot lesions. Contact elk developed neither clinical signs nor gross pathologic lesions of FMD. At necropsy, lesions in bison included numerous extensive vesicles, erosions, and/or ulcers in the oral cavities, feet, and rumen pillars depending on the stage of disease. Less extensive oral, foot, and rumen lesions were present in the inoculated elk. All bison and inoculated elk developed antibodies to FMDV and were positive for FMDV by reverse transcription-polymerase chain reaction (RT-PCR). Transmission occurred between cattle and bison, and bison and bison. It did not occur between elk and cattle. Elk-to-elk transmission studies resulted in only one contact elk developing serologic evidence of a subclinical infection. Other exposed elk developed neither clinical, pathologic, virologic, nor serologic evidence of disease. FMDV was not isolated from animals past 28 days postinfection.

Key words: *Bison bison*, bovidae, cervidae, *Cervus elaphus*, elk, foot-and-mouth disease, pathology, serology.

INTRODUCTION

Foot-and-mouth disease (FMD) has never been diagnosed in bison (*Bison bison*) or elk (*Cervus elaphus nelsoni*) in North America. Little is known about the disease in these species. The disease has been observed in European bison (*Bison bonasus;* Folmer, 1939; Jaczewski, 1960; Podgurniak, 1967), North American bison (Urbain et al., 1938; Hediger, 1940), and hybrids (Folmer, 1939) in European zoos and preserves. The epidemiology and lesions observed in naturally occurring outbreaks of FMD in European bison have been reported (Jaczewski, 1959, 1960; Podgurniak, 1967); however, reports of the disease in North American bison

infected in European zoos are little more than anecdotes. Naturally occurring FMD in red deer (*Cervus elaphus elaphus*) has been reported (Cohrs and Weber-Springe, 1939), and in a series of experimental infections of British deer, including red deer, with FMD virus (FMDV) investigators observed and reported clinical disease (Forman and Gibbs,1974), laboratory findings (Forman et al., 1974), and inter- and intraspecies transmissibility (Gibbs et al., 1975). To our knowledge there are no reports of FMDV infection in North American elk.

In these studies, conducted between August 2002 and December 2004, we attempted to compare the susceptibilities of bison and elk to FMDV, respectively, with that of cattle; characterize the clinical signs and lesions of the disease in these species; determine whether intraspecies and interspecies transmission could occur in bison and cattle, and elk and cattle; determine if standard laboratory tests detect FMDV infection in bison and elk; and determine if bison and/or elk are efficient long-term carriers of the virus. We report here the susceptibility, transmissibility, clinical signs, and lesions of FMD in bison and elk. Microbiologic findings, including results of reverse transcription-polymerase chain reaction (RT-PCR), serologic tests, and virus isolation will be reported separately (unpublished data).

MATERIALS AND METHODS

Bison study

Six yearling, intact, male bison weighing approximately 250 kg each were obtained from a producer located on Long Island, New York, USA, transported to the Plum Island Animal Disease Center (PIADC), Orient, New York, USA (41°10′N, 72°11′W) and placed in biocontainment rooms. Similarly, four 6- to 8-mo-old Holstein cattle steers weighing approximately 200 kg each were obtained from a local vendor, transported to PIADC, and placed in containment. The containment rooms, which housed four and six animals, measured 40 and 95.5 square meters, respectively. Temperature in the rooms was maintained at 25 to 28 C, and rooms experienced 23 to 30 air changes per hour. Bison and cattle were fed alfalfa hay cubes and a mixed grain and molasses feed. Throughout the study cattle and bison, when in the same room, were separated by a single gate and fence partition constructed of steel pipe. All animals were cared for in accordance with the institutional animal care and use guidelines of the PIADC.

After 9 days of acclimation to containment rooms, each bison was immobilized with medatomidine (0.065 mg/kg) and ketamine (1.8 mg/kg) or with medatomidine (0.065 mg/kg) alone delivered intramuscularly (IM) by jabstick or, in the larger containment room, by projectile syringe and dart gun (3 ml dart and JM Special, 11 mm barrel, Dan-Inject®, Sturzelbronn, France). Two steers were sedated with xylazine (0.1 mg/kg) by IM hand injection. Blood samples were collected from all bison and steers. In addition, temperature transmitters (model M3970, modified for intraperitoneal installation, Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA), each having a unique radiofrequency, were installed in the peritoneal cavities of two bison and two steers. The procedure was the following, in brief: following surgical preparation of the left paralumbar fossa and local infiltration of subcutis and musculature with lidocaine, the skin was incised, underlying musculature bluntly dissected in a grid approach, and a 5-cm incision made in the peritoneum. The sterile transmitter was then inserted into the peritoneal cavity, and the incision closed utilizing surgical glue (Vetbond®, 3M Company, St. Paul, Minnesota, USA) and surgical staples.

While immobilized, one bison and one steer were inoculated intraepidermally at four sites on the dorsal surface of the tongue with 0.1 ml inoculum per site of FMDV, strain O1 Manisa. The inoculum for each animal contained 10,000 bovine tongue infective doses (BTIDs) of virus in 0.8 ml minimum essential medium (MEM). All bison and steers received 8 mg/kg oxytetracycline by IM injection, and medatomidine was antagonized with 2 mg/kg tolazoline given by slow intravenous injection.

Beginning 1 hr after recovery, body temperatures of the telemetered bison and steers were monitored remotely every 8 hr from an adjacent hallway using a radio receiver and H antenna (TR 2 receiver, RA-14K antenna, Telonics Inc., Mesa, Arizona, USA) as per the manufacturer's instructions. This remote monitoring allowed temperatures to be measured frequently without entering the room

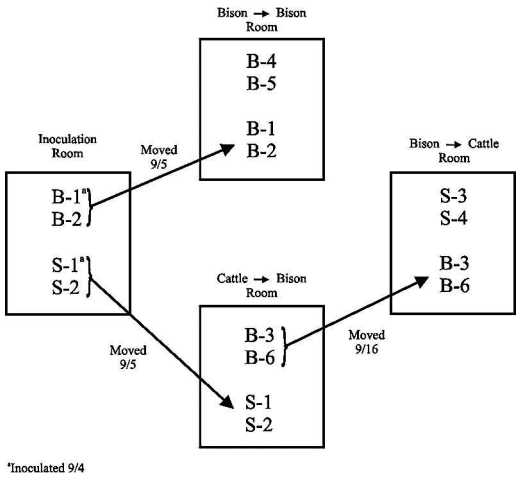

FIGURE 1. Flow diagram depicting housing of bison (B numbers) and cattle (S numbers) with movements of inoculated and exposed animals in bison and cattle transmission studies.

and potentially causing an artifact due to animal handling and immobilization.

In this study, three bison were exposed to the inoculated bison, and two bison and one steer were exposed to the inoculated steer (Fig. 1). The inoculated and contact bison were allowed to commingle with the other bison, but the inoculated and contact steers were separated from the unexposed bison by a steel pipe partition.

Six days after the two bison (B-3 and B-6) exposed to the inoculated and contact steers developed clinical disease, they were placed in a clean room with two unexposed steers. The unanticipated 6-day delay was unavoidable because of logistical reasons in the animal containment building.

Animals were observed daily; cattle were manually restrained and examined while bison were chemically immobilized (medatomidine or medatomidine and ketamine delivered by jabstick or dart gun) and examined, and specimens were collected periodically throughout the study (Table 1). Specimens consisted of blood, biopsies of lesion material, oral swabs, and swabs from lesions. In addition, oropharyngeal secretions were collected using a probang. Laboratory tests included enzyme-linked immunosorbent assay (ELISA), RT-PCR, and virus isolation; results will be reported in a seperate manuscript. After the initial development of fever and clinical signs, pain was mitigated with flunixin meglumine (Banamine®, Schering-Plough, Kenilworth, New Jersey, USA; 1.1–2.2 mg/kg IM as needed).

Bison were euthanized 5, 6, 36, 48, and 49 days postinoculation (DPI) or exposure to infected animals (DPE; Table 1); one bison died 13 DPE. Both steers that showed signs of FMD were euthanized 12 DPI/DPE. The bison were necropsied, and specimens of lung, liver, kidney spleen, heart, pancreas, testis, prepuce, seminal vesicles, rumen, reticulum, abomasum, tongue, buccal tissue, dental pad, palatine tonsil, and lymph nodes (mandibular, parotid, retropharyngeal, tracheobronchial, mediastinal, mesenteric, ileocecocolic, hepatic, and superficial cervical) were collected for microbiologic and histopathologic examinations.

Elk study

A similar but modified protocol was followed in the elk study. Seven female and one male yearling and 2-yr-old elk weighing between 190 and 240 kg each were purchased from a commercial producer in northern New York and transported to PIADC. Four 8- to 9-mo-old Holstein steers weighing approximately 250 kg each were purchased from a local vendor, transported to PIADC, and placed in containment rooms. Rooms contained up to five animals and measured 40 square meters. Animals were fed alfalfa hay cubes and a mixed grain and molasses feed. Elk and cattle were allowed to commingle; the two species were compatible, often grooming each other, and no behavioral difficulties were observed. Animals were allowed to acclimate to containment for 2 wk prior to beginning the study. Temperatures in the female elk were detected by the use of vaginal temperature transmitters (model M3930, ATS, Isanti, Minnesota, USA) monitored by a receiver and datalogger (model R4500S, ATS) programmed to record temperatures every 15 minutes and in all animals for the first 2 wk following inoculation by rectal thermometers once daily.

In this study one steer and three elk were inoculated, four elk and two steers were exposed to inoculated elk, and two elk and one steer were exposed to an infected steer (Fig. 2). One of the elk, E-63, initially exposed to an inoculated elk, was later inoculated. Animals were inoculated by intradermal injection on the dorsal surface of the tongue. The total inoculating dose for each animal was 10,000 BTID in MEM. The tongue was injected at six sites in titrated doses with the most concentrated inoculum given at the rear and a decreasing concentration of virus at each site moving anterior. The original design was to inoculate one elk housed with two contact elk and one steer housed with one contact

TABLE 1. Clinical signs and necropsy results of bison and cattle that developed clinical disease following inoculation or exposure to O 1 Manisa strain of FMDV.

ID[a]	Source of exposure	Onset of clinical signs (DPI/DPE[b])	Clinical signs	Blood/swabs collected (DPI/DPE)	Date of necropsy (DPI/DPE)	Necropsy findings
B-1	Inoculated	1	Fever (41.9 C), chewing, depressed, ptyalism, lameness, oral & foot v/e/u[c]	0, 2	6	Oral/foot/rumen erosions/ulcers, myocarditis, focal pneumonia
B-2	B-1		Fever (41.8 C), lameness, ptyalism, depressed, oral & foot v/e/u	0, 5, 22, 35	49	Coronary band ulcers, mild focal pneumonia
B-3	S-1		Fever (ND),[d] nasal discharge, wet chin, mildly depressed, oral & foot v/e/u	0, 4, 11, 21, 34	36	Small oral/esophageal ulcers, aspiration pneumonia, coronary band ulcers
B-4	B-1		Fever (ND), depressed, reluctant to rise, oral & foot v/e/u	0, 4, 13	13	Healing oral/foot erosions/ulcers, severe aspiration pneumonia
B-5	B-1		Fever (ND), nasal discharge, ptyalism, chewing, teeth grinding, depressed, diarrhea, lameness, oral & foot v/e/u	0	5	Oral foot v/e/u, aspiration pneumonia, coccidiosis
B-6	S-1		Fever (ND), clear nasal discharge, oral & foot v/e/u	0, 4, 12, 21	48	Tendonitis, arthritis, synnovitis, pneumonia, coronary band ulcers
S-1	Inoculated	2	Fever (39.7 C), depressed, chewing, teeth grinding, ptyalism, lameness	0, 2, 5, 6, 12	12	Oral/foot erosions/ulcers, nares & oral & foot v/e/u
S-2	S-1		Fever (41.4 C), depressed, chewing, teeth grinding, ptyalism, lameness, nares & oral & foot v/e/u	0, 2, 5, 6, 12	12	Oral/foot erosions/ulcers

[a] B numbers = bison; S numbers = cattle (steers).

[b] DPI/DPE = days postinoculation/days postexposure.

[c] v/e/u = vesicles/erosions/ulcers.

[d] ND = no data.

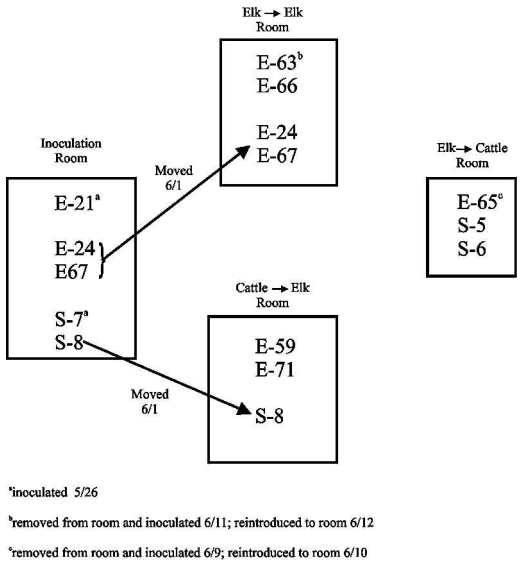

FIGURE 2. Flow diagram depicting housing of elk (E numbers) and cattle (S numbers) with movements of inoculated and exposed animals in elk and cattle transmission studies.

steer. When the contact animals exposed to the inoculated elk developed fever or other evidence of disease they would be moved to clean rooms to expose the naïve animals, and the inoculated animals would be euthanized and necropsied. This worked well with the cattle, but because the uninoculated contact elk, exposed to the inoculated elk, failed to develop clinical evidence of disease, two additional elk were inoculated and, on the day following inoculation, placed in the rooms with the naïve elk and steers.

Animals were examined daily for lesions, and specimens for serology, virus isolation, and RT-PCR were collected prior to inoculation or exposure to FMD inoculated animals. After inoculation or exposure, specimens were collected every other day for 8 days and weekly thereafter. Specimens included blood in heparin, blood in EDTA, whole blood, oral and nasal swabs, lesion material, and oropharyngeal fluid collected with a probang. Elk were sedated with 15–25 mg xylazine by IM hand injection prior to examination and sampling. Xylazine was antagonized with yohimbine (0.125 mg/kg) given intravenously as needed. Laboratory tests included ELISA, RTPCR, and virus isolation and were reported by Ward et al. (in press). After the initial development of fever and clinical signs, pain was mitigated with flunixin meglumine (1.1–2.2 mg/kg IM as needed).

Elk and cattle were euthanized and necropsied between 6 DPI and 56 DPE. At necropsy specimens of lung, liver, kidney, spleen, pancreas, heart, oropharynx, palatine and pharyngeal tonsils, rumen, tongue, foot and oral lesions, and lymph nodes (medial and lateral retropharyngeal, tracheobronchial, mediastinal, mesenteric, internal iliac, and mandibular) were collected for histopathologic and microbiologic examinations. Specimens for histopathology from bison and elk studies were collected in 10% neutral buffered formalin, treated in a series of formalin and ethanol solutions, and shipped to the National Veterinary Services Laboratories in Ames, Iowa, USA, for routine processing and histopathologic examination.

RESULTS

Bison study

The inoculated steer and the steer exposed to the inoculated steer developed clinical signs typical of FMD. The inoculated bison and the three bison exposed to the inoculated bison as well as the two bison exposed to the infected steers all developed clinical signs and lesions typical of FMD (Table 1). For steers and bison, these included fever, depression, lameness with reluctance to stand, nasal discharge, ptyalism, inappetence, chewing movements, teeth grinding, and oral and foot lesions that progressed from vesicles to erosions and, in some cases, ulcers. Fevers in the two bison with intra-abdominal temperature transmitters reached 41.9 and 41.8 C 1.5 DPI and 3 DPE, respectively, and remained consistently elevated for 1 wk. Fevers in the two cattle with temperature transmitters peaked at 39.5 and 41.4 C 2 DPI and 5 DPE, respectively. Clinical signs in bison were similar to those in cattle but were more difficult to observe because of the stoic behavior of the bison. Signs such as depression and lameness were best observed through the containment room window under diminished light prior to entering the room.

Lesions of the feet in cattle and bison were first detected in the interdigital space, often near the heels, and progressed to involve most of, or the entire,

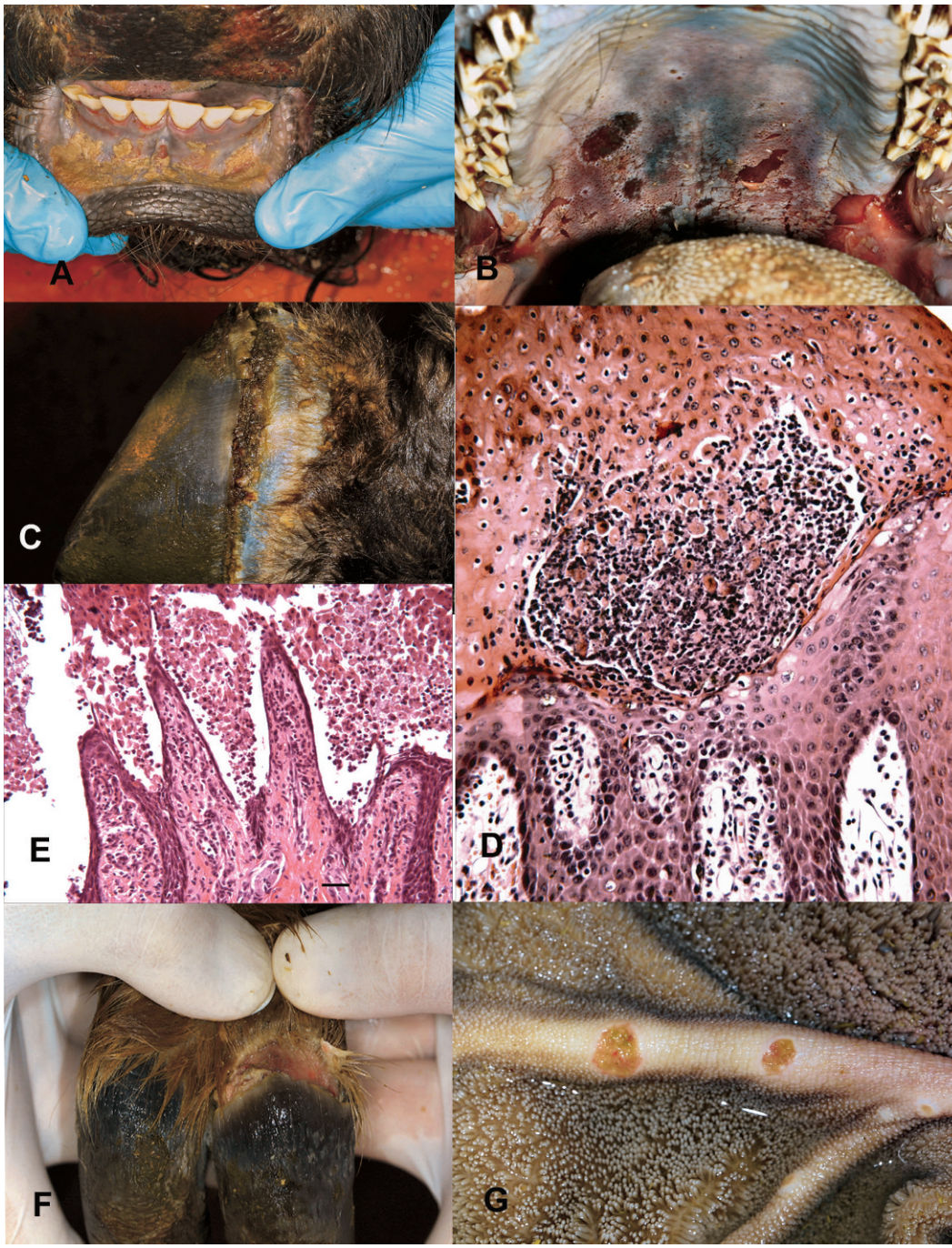

FIGURE 3. A. Bison no. 4, 13 DPE to FMDV with erosions visible on tongue tip and labial mucosa anterior to the incisors. B. Bison no. 4, 13 DPE to FMDV with erosions on palate. C. Bison no. 6, 48 DPE to FMDV with circumferential hoof deformity 1 cm below coronary band. D. Bison no. 1, 6 DPI with FMDV; microscopic lesion of tongue epithelium located in stratum spinosum. Lesion contains detached degenerating epithelial cells, leukocytes, and degenerating cellular detritus. H&E. Bar = 50 mμ. E. Bison no. 5, 5 DPE to FMDV; vesicle of palate epithelium. Lesion has loss of all but basal layer of epithelium; vesicle contains detached degenerating epithelial cells and leukocytes and is covered by overlying epithelial "cap." H&E. Bar

coronary band. Cattle developed encrusted erosions on the nares and on the muzzle accompanied by serous, mucoid, or mucopurulent nasal discharge. Nasal lesions were less severe in the bison; mild serous to mucoid nasal discharge was noted. Tongue lesions in the cattle consisted of 3 to 6 cm vesicles, which coalesced, ruptured, and became denuded, leaving large portions of the tongue eroded. Bison had smaller tongue lesions ranging in size from 0.5 to 4 cm. Cattle and bison developed lesions on the dental pad, gingival mucosa, buccal and labial mucosa, especially anterior to the dental pad and incisors (Fig. 3A), and hard and soft palates (Fig. 3B).

Within 14 days postinoculation or postexposure, cattle and bison regained normal feed consumption, alertness, and activity. Lameness persisted in one bison for 4 wk.

At necropsy, the bison that died 13 DPE had severe aspiration pneumonia. Three other bison also had post-mortem evidence of mild-to-moderate bronchopneumonia. Bison that were necropsied 36, 48, and 49 DPE had circumferential hoof wall deformities (Fig. 3C). Other gross lesions in the bison were similar to those of cattle with FMD (Table 1).

On histopathologic examination, tissues from B-5 and B-1, killed 5 DPE and 6 DPI, respectively, had vesicles and erosions involving palate, tongue, and interdigital epithelium of the foot. Small epithelial lesions were characterized by focal ballooning degeneration involving cells in the stratum spinosum (Fig. 3D). Focal cellular necrosis was accompanied by focal infiltrates of neutrophils and edema. Larger lesions showed progression and coalescence of necrosis to produce intraepithelial bullae covered by vesicular caps of superficial epithelium. Mature vesicles were overlaid with an intact layer of keratinocytes or, if ruptured, coagula containing detached keratinocytes, amorphous eosinophilic material, neutrophils, and bacteria. In many cases, erosions extended deep to involve all but the basal epithelium, which often was flattened and deeply basophilic (Fig. 3E). In some lesions there were focal necrosis and loss of the basal epithelium with marked mixed inflammatory cell infiltrates in the subjacent dermis or submucosa. Sections from the rumen lesion in B-1 had marked loss of epithelium with preservation of the basal layer. The erosion was overlaid with a coagulum of neutrophils, degenerate cellular debris, mineralized microliths, and amorphous eosinophilic material. Both animals had focal bronchopneumonia with associated plant material in the pneumonic lesions. Bison B-1 had focal myocarditis surrounding and involving a Purkinje fiber characterized by marked focal infiltrates of small and large mononuclear cells surrounding and infiltrating the Purkinje fiber with focal degeneration of individual cells in the Purkinje fiber.

Sections of tongue and buccal and palatine mucosa from bison B-3, B-6, and B-2 that were euthanized and necropsied 36, 48, and 49 DPE, respectively, had no lesions. Remaining foot lesions from these bison consisted of focal ulceration of the coronary band accompanied by marked infiltrates of mixed inflammatory cells and granulation tissue in the denuded dermis. The heart from bison B-2 had focal myofiber degeneration and sarcolemmal proliferation. Lung sections from these animals had focal bronchopneumonia. Bison B-4, which died 13 DPE, had severe

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= 50 mμ. F. Elk no. 65, 8 DPI with FMDV; deep erosion above bulb of heel. This was the most severe lesion seen in the elk. G. Elk no. 65, 8 DPI with FMDV; deep erosions on rumen pillar. http://jwd.allentrack.net/jwdi_files/2007/09/21/00000575/01/575_1_fig_1_jnw9nc.pdfhttp://jwd.allentrack.net/jwdi_files/2007/09/21/00000575/01/575_1_fig_0_jwxr2j_small.pdf

TABLE 2. Clinical signs and necropsy results of elk and cattle, inoculated with or potentially exposed to O 1 Manisa strain of FMDV.

ID[a]	Source of exposure	Onset of clinical signs (DPI/DPE)[b]	Clinical signs	Date of necropsy (DPI/DPE)	Necropsy findings
E-21	Inoculated	3	Fever (40.3 C), mild lameness, ptyalism, focal oral & foot v/e/u[c]	6	Oral/foot/rumen erosions/ulcers
E-63	Inoculated	3	Fever (40.6 C), mild lameness, focal foot v/e/u	40	Healing rumen erosions/ulcers
E-65	Inoculated	3	Fever (40.5 C), mild lameness, tongue & focal foot v/e/u	8	Rumen ulcers, foot erosions
E-24	E-21 & E-63	NA[d]	None	56	NSL[e]
E-59	S-8	NA	None	51	NSL
E-66	E-63	NA	None	39	NSL
E-67	E-21 & E-63	NA	None	56	NSL
E-71	S-8	NA	None	51	NSL
S-5	E-65	NA	None	41	NSL
S-6	E-65	NA	None	7	NSL
S-7	Inoculated	1	Fever (40.8 C), lameness, ptyalism, nasal, discharge, depressed, oral & foot v/e/u	6	Oral/foot erosions/ulcers
S-8	S-7	3	Fever (40.8), lameness, ptyalism, depressed, nasal, oral, & foot v/e/u	22	Oral/foot erosions/ulcers

[a] E numbers = elk; S numbers = cattle (steers).

[b] DPI/DPE = days postinoculation/days postexposure.

[c] v/e/u = vesicles/erosions/ulcers.

[d] NA = not available.

[e] NSL = No significant lesions.

aspiration pneumonia; tissues were moderately to markedly autolyzed.

Elk study

The inoculated steer and the steer exposed to the inoculated steer developed clinical signs of FMD including fever, transient inappetence, lameness, marked ptyalism, nasal discharge, and oral and foot vesicles progressing to erosions and ulcers (Table 2). All six of the titrated tongue inoculation sites in the steer developed large vesicles one DPI; whereas in the elk, only the three inoculation sites receiving the highest concentrations of virus developed lesions, which were characterized as "dry." These lesions were pale yellow to white circular flat lesions, which subsequently eroded. Oral vesicles were never observed in the elk. The three inoculated elk developed fever beginning 2 DPI, which peaked (40.3–40.7 C) on 3 or 4 DPI and persisted another 2–4 days. Other signs consisted of mild pytalism in one elk, transient shifting leg lameness with reluctance to rise in two elk, transient mild inappetence, tongue lesions other than at injection sites in two of the inoculants, and coronary band vesicles progressing to erosions and, in some cases, ulcers on one or more feet. One of the three elk exposed to inoculated elk had mild shifting leg lameness and mild pytalism. Neither that elk nor other exposed elk had detectable lesions of FMD. The two steers exposed to FMD-inoculated elk developed no clinical signs or lesions of FMD.

At necropsy, inoculated elk examined 6, 8, and 42 DPI had the following: (6 DPI) healing inoculation lesions, a 3-cm diameter erosion on the dorsal surface of the ball of the tongue, erosion of coronary band of one dewclaw, and subtle vesicu-

lation and undermining of the coronary band on front feet; (8 DPI) a 1-cm diameter scar on the ball of the tongue, ruptured vesicles with segmental erosion of the coronary bands involving the heels (Fig. 3F) and interdigital space on right front and right rear feet and six 1–2 cm diameter round-to-oval erosions and ulcers on the rumen pillars (Fig. 3G); and (42 DPI) five 1–3 cm healing ulcers on the rumen pillars.

Necropsy of the inoculated steer and contact steer that developed clinical FMD revealed the following: (6 DPI) multiple intact and eroded vesicles involving the tongue, gingiva, and palate, and circumferential vesiculation of the coronary bands and interdigital spaces of claws and dewclaws on all feet; and (22 DPE) scant scarring of the tongue, a few 0.5–2 cm erosions on the hard and soft palate, and circumferential ulceration of the coronary band involving all feet. At necropsy, no gross lesions were seen in the three elk exposed to the inoculated elk, in the two elk exposed to the infected contact steer, or in the two steers exposed to the inoculated elk.

Histopathologic examination of tissues from the inoculated elk (nos. 21, 63, and 65) necropsied 6, 8, and 40 DPI, respectively, showed oral, rumen pillar, and coronary band erosions with focal ulceration (6 and 8 DPI) similar to the early bison lesions; and a rumen pillar lesion consisting of focal acanthosis and hyperkeratosis accompanied by a moderate infiltrate of mixed inflammatory cells in the subjacent submucosa. This was interpreted as a healing erosion. Tongue lesions, which on gross observation were considered "dry," histologically consisted of a zone of epithelial necrosis in the stratum spinosum, which lacked edema and elevation of the overlying epithelium.

DISCUSSION

In this study, the susceptibility of North American bison to FMDV strain O1 Manisa was similar to that of cattle. Fever and lesions in the inoculated bison and steer began to develop 24 hr postinoculation and followed in the exposed bison 1 day later. The exposed steer developed lesions 5 days later. All bison exposed to infected bison or steers developed clinical signs of FMD. The failure of infected bison to transmit the infection to naïve steers housed in the same animal room was likely due to the unavoidable 5-day delay in exposing the steers following the onset of signs in the bison. The peak aerosol shedding of FMDV from infected cattle occurs early in the course of the infection, concurrent with development of early clinical disease (Donaldson and Alexanderson, 2002). It is likely that the infection in bison is similar to that in cattle in this regard, and the major virus shedding had already occurred in the bison at the time they were placed in the room with the unexposed cattle.

Clinical signs in the bison were similar to those in the cattle with the following minor exceptions: Tongue vesicles and erosions in bison were smaller than those in cattle, and the loud smacking sounds made by the cattle as the large lingual vesicles were developing were not observed in the bison. With the onset of fever and early lesion development, the cattle displayed marked depression characterized by a dropped head position, and a dull unresponsive demeanor accompanied by some vocalization. In bison, the depressed attitude was observable only when the animals were unaware of the observers' presence. Once aware of the observer, the bison displayed an alertness and stoicism that might mask clinical disease without closer examination. During the first week of infection, the cattle had serous to mucopurulent nasal discharge and marked ptyalism with long strings of thick ropey saliva suspended from the chin. This was much less evident in the bison.

On post-mortem examination, gross and histopathologic findings of oral and foot

lesions in the bison and the cattle were consistent with those reported for cattle (Seibold, 1963), including microscopic epithelial lesions as described by Gailiunas (1968), and European bison (Podgurniak, 1967). Vesicular and erosive lesions on the rumen pillars were noted in FMDV-infected European bison (Podgurniak, 1967) and other species. Myocarditis, characterized by myofiber necrosis, often accompanied by mononuclear cell infiltrates, has been observed in several species including European bison (Podgurniak, 1967), and myocardial disease due to degeneration of the myocardium and conduction system has occurred in convalescent cattle (Barker et al., 1993). The occurrence of pneumonia often with associated plant material in airways is considered a likely sequel to multiple chemical immobilizations resulting in aspiration of rumen contents. Safety restrictions at PIADC precluded the use of narcotics, which necessitated the use of drug combinations that included ketamine, for which there is no antagonist. Despite preventative efforts by the investigators, regurgitation of the rumen contents was occasionally observed. Interestingly, in an FMD outbreak in bison in Poland in which the animals were not chemically restrained, pneumonia was also a common sequel to the infection (Podgurniak, 1967). Persistent lameness and ulcerative foot lesions, as we observed, were also reported in the European bison (Jaczewski, 1959).

In the experimental infection of elk and cattle with FMDV, strain O1 Manisa, very different results were observed in the two species concerning the susceptibility to infection and the efficiency of transmission of infection. Inoculated cattle and cattle exposed to inoculated cattle rapidly developed clinical signs and lesions of FMD. Inoculated elk developed mild disease characterized by fever, inoculation site lesions on the tongue, and limited tongue lesions not involving inoculation sites, as well as limited foot lesions. Whereas cattle developed circumferential vesiculation and erosion of the coronets of both claws and dewclaws, elk developed lesions on one or two feet involving only a portion of the coronary band. This was usually at the heels and in two elk involved a portion of the coronet of the dewclaws. Ptyalism and lameness in the elk was observable only with close observation.

The most striking result in the elk study was the relative resistance to infection of the elk and the inability of the inoculated elk to transmit infection to other elk or to commingled cattle. In the cattle-to-elk transmission portion of the study, an exposed steer was commingled with elk on the first day of the steer's fever; the steer subsequently developed severe clinical signs of FMD. Similarly, in the elk-to-cattle portion, an elk was inoculated and immediately placed in a room containing other elk and an unexposed steer. In both rooms, animals were commingled and shared feed and water. In neither case did interspecies transmission occur.

Of the five exposed, uninoculated elk, only one showed serologic evidence of virus replication developing antibody to viral nonstructural protein (unpublished data). That animal, unfortunately, was the male, precluding the prior installation of a vaginal temperature transmitter. Rectal temperatures of that elk taken daily never exceeded 39.5 and on daily observation no clinical signs of FMDV infection were noted. Additionally, no lesions were observed at necropsy done 50 DPE.

In summary, these two studies comparing the infection of FMDV, strain O1 Manisa, in bison and elk with that in cattle showed marked differences in susceptibility to the infection and efficiency of transmission in bison and elk. The disease in bison was similar to that in cattle. Bison were readily infected when exposed to infected bison or cattle. Clinical signs and lesions in bison were similar to those in cattle, though clinical disease in bison was less evident due to the animals' stoicism when being observed. Inoculation of

FMDV, strain O1 Manisa, in elk, however, produced only mild clinical disease, and elk were neither susceptible to infection by exposure to infected cattle or elk nor efficient at transmitting the infection to cattle. Only one of the five exposed, uninoculated elk developed serologic evidence of virus replication, and infection in that animal was subclinical.

The two experiments were considered pilot in their nature in order to establish indications about the susceptibility of these two species to FMDV and to determine the value of the conventional diagnostic tests. The studies were limited in the number of animals used; therefore comparison of the findings cannot be considered.

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