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Citation for published version:
Morgan, KL, Handel, IG, Tanya, VN, Hamman, SM, Nfon, C, Bergman, IE, Malirat, V, Sorensen, KJ & Bronsvoort, M 2014, 'Accuracy of Herdsmen Reporting versus Serologic Testing for Estimating Foot-and-Mouth Disease Prevalence' Emerging Infectious Diseases, vol 20, no. 12, pp. 2048-2054. DOI: 10.3201/eid2012.140931

Digital Object Identifier (DOI):
10.3201/eid2012.140931

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Emerging Infectious Diseases

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Accurancy of Herdsmen Reporting versus Serologic Testing for Estimating Foot-and-Mouth Disease Prevalence

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Herdsmen-reported disease prevalence is widely used in veterinary epidemiologic studies, especially for diseases with visible external lesions; however, the accuracy of such reports is rarely validated. Thus, we used latent class analysis in a Bayesian framework to compare sensitivity and specificity of herdsmen reporting with virus neutralization testing and use of 3 nonstructural protein ELISAs for estimates of foot-and-mouth disease (FMD) prevalence on the Adamawa plateau of Cameroon in 2000. Herdsmen-reported estimates in this FMD-endemic area were comparable to those obtained from serologic testing. To harness to this cost-effective resource of monitoring emerging infectious diseases, we suggest that estimates of the sensitivity and specificity of herdsmen reporting should be done in parallel with serologic surveys of other animal diseases.

Owner-, farmer-, or herdsman-reported disease prevalence is widely used in veterinary epidemiologic studies (1–6), especially for diseases that produce visible external lesions (e.g., ovine myiasis, foot-and-mouth disease [FMD]) (1,5) or characteristic clinical signs (e.g., scrapie) (7). For such interview- or questionnaire-based reporting, a common criticism is lack of external validation because questionnaires, like other measuring devices, need to be calibrated. External validation is usually approached by comparing questionnaire data with data measured by other methods such as visual inspection (8–10), photographs (11), selection of clinical signs (2,4), laboratory test results (12), or other (4,13). These approaches, however, are difficult to use in poorer countries and pastoral populations, where there are limited resources and no comparison data. We estimated sensitivity and specificity of herdsmen-reported FMD prevalence in the Adamawa plateau, Cameroon, and compared herdsmen’s estimates with serologic test results.

FMD is a highly contagious viral disease of even-toed ungulates, caused by FMD viruses in the family Picornaviridae. Globally, FMD is a major disease of livestock because it leads to production losses and restrictions on trade with FMD-free countries (14). Clinical signs in cattle are distinct: vesicles on the tongue, gums, coronary band, and occasionally, udder. Animals salivate and are febrile, lame, and inappetant. Ruptured vesicles leave ulcers with characteristic underrun epithelial tissue at the edges (15).

To assess herdsmen’s ability to correctly identify FMD and to compare the sensitivity and specificity of herdsmen reporting with that of serologic testing, we conducted a cross-sectional study of FMD on the Adamawa plateau, the major cattle-rearing area of Cameroon. We used a structured questionnaire, administered by interview, to determine whether herdsmen had seen FMD in their herds in the previous 1 and 2 years (5,16). Their ability to correctly identify FMD was also assessed by showing them color photographs of typical lesions. To estimate the sensitivity and specificity of the various estimates, we used Bayesian latent class models. These estimates were...
arrived at by restricting the age of cattle analyzed by virus neutralization (VN) testing to <2 years and by adopting evidence that nonstructural protein (NSP) antibody titers fall more rapidly (over ≈1 year) than VN antibodies (17,18). The study was conducted in accordance with the Cameroonian Ministry of Research guidelines and with approval from the University of Liverpool ethics committee in 1999.

Materials and Methods

Study Population

The study population is described elsewhere (5). In brief, a database of 13,006 herds was constructed from rinderpest vaccination records from 88 veterinary centers across the Adamawa region. This region is ≈64,000 km², lies between latitudes 6°N and 8°N, and is divided into 5 administrative divisions (Vina, Mbere, Mayo Banyo, Djerem, and Faro and Deo).

Study Design

We used a cross-sectional study design and 2-stage stratified random cluster sample to select 147 herds in 2000. The sample size was chosen to enable a herd seroprevalence of 50% to be estimated with 9% accuracy and 90% confidence; we increased the number of samples selected by 10% (inflation) to allow for refusals (5).

From each herd, a minimum of 5 adult (>24 months) and 5 juvenile (8–24 months) cattle were randomly sampled (5,16). We used samples from juvenile cattle only. With a sample of this size, the probability of detecting at least 1 seropositive animal in a herd of 70 was 95%, assuming within-herd seroprevalence of 50% and test sensitivity and specificity of 100% each. The lower age limit was set at 8 months to minimize misclassification associated with maternal antibodies. In herds with <5 animals in the appropriate age group, all animals in that group were sampled. The number of animals presented for sampling from each herd was 7–81 (median 35, mean 37.4).

Sampling

Blood was collected by jugular venipuncture into 10-mL Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ, USA), allowed to clot, and then separated in a 12-volt portable field centrifuge (Vulcon Technologies, Grandview, MO, USA). Serum was collected into two 1.8-mL cryovials (Nunc, Roskilde, Denmark) and kept at 4°C in a portable gas refrigerator for up to 14 days before being frozen and stored at –20°C. Samples were transported on dry ice to the World Reference Laboratory for Foot-and-Mouth Disease in Pirbright, UK, and stored at –20°C.

Questionnaire

To collect data from herdsmen, we used a structured, interview-based questionnaire, administered in Fulfulde (the language of the Fulani people) (5,19). The questionnaire asked whether respondents had observed FMD in their herd in the previous year and (separate question) in the previous 2 years.

Photographs

Herdsmen were asked to identify the diseases shown in 3 A4-sized photographs: a bovine tongue with a ruptured FMD vesicle, a bovine foot with ruptured FMD vesicles, and a bovid with lumpy skin disease (Capripoxviridae, Poxviridae). The interviewer oriented the viewer as to what was on the photograph, pointing out relevant anatomic, but not pathologic, features. A herdsman was described as being able to recognize FMD if he identified at least 1 of the FMD photographs correctly and either identified or recognized lumpy skin disease as not being FMD.

ELISA Testing

To test for antibodies against NSP, we used 3 ELISAs: indirect (I)–ELISA, CHEKIT-ELISA, and competitive (C)–ELISA. Each is described below.

For screening with the I-ELISA 3ABC (I-ELISA), aliquots of heat-treated serum (56°C for 2 h) were sent to Panaftosa, Brazil. This test is described elsewhere (22,23). Two samples had insufficient serum for the I-ELISA, so this testing was performed for 1,375 animals, 651 of which were 8–24 months of age.

The CHEKIT-3ABC-FMD ELISA (CHEKIT-ELISA) is described elsewhere (23). Testing was performed by author B.M.de C.B. at the World Reference Laboratory for Foot-and-Mouth Disease, according to the manufacturer’s instructions.

The C-ELISA was performed as described (24,25). Testing was conducted by author K.J.S. at the Danish Institute for Food and Veterinary Research in Kalvehave, Denmark.

Comparison of Herdsman Reporting and Serologic Testing

First, herdsmen’s reports of disease in their herd in the previous 2 years were compared with VN test results for cattle 8–24 months of age in the same herd. Second,
herdsmen’s reports of disease in the previous year were compared with antibodies against NSP determined by all 3 NSP ELISAs.

**Statistical Analyses**

Prevalence estimates were conducted by using STATA version 6.0 (http://www.stata.com). To avoid bias in point and variance estimates, we incorporated stratification and cluster effects with svymean or svyprop commands and strata (administrative division), psu (veterinary center), and pweight (probability weightings) (5).

Sensitivity and specificity of serologic testing and herdsmen reporting were estimated by using a Bayesian latent Gibbs Sampler (http://mcmc-jags.sourceforge.net/) software package in R. This technique requires use of at least 2 tests that are conditionally independent (i.e., that if the true disease status of an animal was known, the outcome of 1 test would not influence the probability of a positive or negative result in the other). This technique also requires that prior distributions are specified for test properties and prevalence. The serologic tests were assigned a prior distribution of β (3,1) according to previous estimates of sensitivity and specificity (23). Herdsmen’s reports were assigned an uninformed distribution of β (1,1), which is equivalent to a uniform distribution between 0 and 1 and implies no prior knowledge of test performance.

Sensitivity and specificity were estimated by using a Markov chain Monte Carlo technique and Gibbs sampling (28,29), which involves sampling from the posterior distribution of interest and calculating the relevant measures (e.g., means, medians, and standard deviations of the parameters). This iterative procedure involves burn-in, checking for convergence of the sample chain, and then sampling from the posterior distribution. In this model, the first 50,000 iterations were discarded as burn-in, and every 100th of the following 200,000 iterations were kept for posterior inference. Convergence was assessed by visual inspection of the time-series plots for the parameters and by using Gelman and Rubin diagnostic plots from 3 sample chains with different starting values (30).

The posterior means, medians, and 95% credibility intervals (PCIs) for sensitivity, specificity, and prevalence were calculated. Because no differences between means and medians were found, means were reported; the primary results were 95% PCIs.

When comparing herdsmen’s reports of FMD in the previous 2 years with VN test results, sensitivity and specificity could not be allowed to vary across populations because there were only 2 tests. However when 3 NSP tests were used, sensitivity and specificity of herdsmen’s reports were allowed to vary across populations, depending on factors such as whether the herdsmen watched the animals daily, whether the owner was of Fulani or Mbororo ethnicity, or whether the herdsmen could recognize FMD lesions from pictures. To examine differences between prevalence and disease recognition in photographs, we used χ² testing.

**Results**

**Response Rate**

Of the 147 herds selected, 146 (99.3%) were sampled. Flooding prevented access to 1 herd. Blood was collected from 1,377 animals, 651 of which were 8–24 months of age (142 herds). One herd was excluded because antibody test results were missing, leaving 141 herds from which blood was collected.

**FMD Prevalence during Previous 2 Years**

Herdsmen reported that 78.2% herds had been infected with FMD at least once during the previous 2 years. VN testing results indicated an estimated 80.3% prevalence (Table 1). Prevalence estimated by both methods differed among administrative divisions. FMD in the previous 2 years was reported by all herdsmen in Faro and Deo but by

### Table 1. Prevalence of FMD among cattle, Adamawa plateau, Cameroon, according to different surveillance methods, 2000*

| Administrative division | Prevalence 2 years, % (95% CI)† | Prevalence 1 year, % (95% CI)† |
|-------------------------|---------------------------------|---------------------------------|
|                         | Herdsmen’s reports | VN testing | Herdsmen’s reports | I-ELISA | CHEKIR-ELISA | C-ELISA |
| Vina                    | 89.6 (83.0–96.1) | 85.1 (76.4–93.8) | 76.6 (66.4–86.8) | 74.5 (64.9–84.0) | 29.8 (16.3–43.2) | 70.2 (58.6–81.8) |
| Mbere                   | 72.0 (55.0–89.0) | 76.0 (57.0–95.0) | 54.4 (32.6–76.1) | 50.8 (33.0–68.8) | 15.8 (1.8–29.7) | 56.1 (32.6–79.7) |
| Djerem                  | 54.8 (34.7–74.9) | 59.2 (48.0–70.6) | 35.7 (19.1–52.3) | 55.4 (45.0–65.7) | 1.7 (1.7–30.4) | 37.5 (24.1–50.9) |
| Mayo Banyo              | 76.8 (66.0–91.2) | 85.7 (76.2–95.2) | 43.9 (22.5–65.4) | 59.1 (39.4–78.8) | 12.1 (0.7–23.5) | 63.8 (44.5–82.8) |
| Faro and Deo            | 100 (72.1–84.3) | 100 (75.0–85.6) | 73.3 (62.2–84.5) | 73.3 (52.4–94.3) | 40.0 (28.8–51.2) | 73.3 (52.4–94.2) |
| Overall                 | 78.2 (67.4–88.4) | 80.3 (65.6–85.6) | 57.4 (48.8–65.1) | 63.0 (56.2–69.9) | 21.8 (15.6–28.0) | 60.4 (52.6–68.2) |

†FMD, foot-and-mouth disease; VN, virus neutralization.

†CIs adjusted for stratification by administrative division and clustering of herds by veterinary center.
only 55% in Djerem. Prevalence estimates obtained by VN testing were similar (Table 1).

**FMD Prevalence during Previous Year**

For the previous year, ~60% of herdsmen reported having noticed FMD in their herds. This prevalence estimate was similar to that obtained by I-ELISA and C-ELISA but considerably more than that estimated by CHEKIT-ELISA (Table 1). The differences in reported prevalence among administrative divisions for the previous 2 years were also found for the previous year. (Table 1)

**Sensitivity and Specificity**

Overall sensitivity of herdsmen’s reports of FMD in the past 2 years was 95.7% (95% CI 88.7%–99.8%) and specificity was 60% (95% CI 44.3%–77.5%). These rates were remarkably similar to those determined by VN testing for serum antibodies in juvenile cattle (sensitivity 95.2% [95% PCI 89.6%–99.1%] and specificity 59.9% [95% PCI 45.6%–77.2%]).

Overall sensitivity of herdsmen’s reports of FMD in the previous year was 84.0% (95% CI 75.1%–92.2%) and specificity was 75.1% (95% CI 62.7%–85.1%). Sensitivity of herdsmen’s reports was significantly lower than that of I-ELISA (97.1% [95% PCI 91.0%–99.9%]) and C-ELISA (97.5% [95% PCI 91.9%–99.9%]). Specificity of herdsmen’s reports was also slightly lower than that of I-ELISA (79.6% [95% CI 68.0%–89.6%]) and C-ELISA (86.5% [95% CI 75.1%–95.7%]) but not significantly so. Sensitivity was poor for CHECKIT-ELISA (37.2% [95% PCI 27.0%–48.1%]), but specificity was high (92.8% [95% PCI 85.0%–98.1%]).

Differences among administrative divisions were marked. The sensitivity of herdsmen’s reports was highest for Vina (94.3%) and lowest for Djerem (57.8%); specificity was highest for Mayo Banyo (92.0%) and lowest for Faro and Deo (33.1%) (Table 2).

Sensitivity, but not specificity, of herdsmen’s reports differed among ethnic groups. Sensitivity was greater for the Fulani (90.3% [95% PCI 87.8%–98.0%]) than for the Mbororo people (73.8% [95% PCI 57.5%–87.5%]); p < 0.001. Specificity for the Fulani was 72.4% (95% PCI 53.2%–88.2%) and for the Mbororo was 76.4% (95% PCI 60.4%–89.5%).

Reporting accuracy did not differ between herd owners and nonowners. Sensitivities were 79.3% (95% CI 61.2%–92.8) and 82.9 (95% CI 71.8%–92.2%), and specificities were 73.7% (95% PCI 52.0%–91.5%) and 74.4% (95% PCI 59.8%–86.8%), respectively.

Similarly, reporting accuracy did not differ between respondents who watched cattle daily and those who did not. Sensitivities were 88.5% (95% CI 75.6%–97.3%) and 76.9% (95% PCI 63.9%–88.2%), and specificities were 71.9% (95% PCI 49.6%–89.7%) and 75.1% (95% PCI 60.6–87.5%), respectively.

**Herdsmen Identification of FMD in Photographs**

FMD was correctly identified on 1 of 2 photographs by more than two thirds (69.3% [95% CI 61.4%–77.2%]) of herdsmen; 60.4% (95% CI 53.2%–67.7%) correctly identified FMD tongue lesions, 65.2% (95% CI 57.6%–72.8%) FMD foot lesions, and 55.8% (95% CI 47.8%–63.8%) both. Only 20.9% (95% CI 12.9%–28.8%) correctly identified FMD lesions in all 3 photographs. Lumpy skin disease was recognized by 28.5% (95% CI 19.9). Almost a quarter (24.3% [95% CI 17.1%–31.6%]) were unable to recognize FMD or lumpy skin disease from photographs.

Herd ownership did not influence ability to recognize FMD from photographs. FMD was recognized in photographs by 68.5% (95% CI 60.0%–76.9%) of owners and 71.3% (95% CI 58.5%–84.1%) of nonowners (p = 0.675).

Ethnicity affected the ability to recognize FMD from photographs. FMD lesions were recognized by a greater proportion of Fulani (82.2% [95% CI 72.3%–92.3%]) than Mbororo (58.8 % [95% CI 44.1%–73.6%]) herdsmen; p = 0.0143.

Frequency of herd observation did not influence ability to recognize FMD from photographs. FMD lesions were recognized by 66.1% (95% CI 51.9%–80.2%) of those who watched the animals daily and by 70.7% (95% CI 61.2%–79.3%) of those who did not (p = 0.537).

Administrative region did affect ability to recognize FMD from photographs. Recognition of FMD lesions in photographs was highest for herdsmen in Vina (79.2% [95% CI 67.1%–91.2%]) and lowest for those in Mayo Banyo (53.3% [95% CI 19.2%–87.5%]); these differences were not statistically significant (p = 0.354). FMD lesion recognition was 72.3% (95% CI 57.4%–89.3%) for herdsmen in Mbere, 59.4% (95% CI 38.9%–79.8%) in Djerem, and 68.2% (95% CI 51.6%–84.8%) in Mayo Banyo.

**Table 2. No–gold standard estimation of herd-level sensitivity and specificity of herdsmen reporting of FMD in administrative divisions of the Adamawa plateau, Cameroon**

| Administrative division | Sensitivity, % (95% PCI) | Specificity, % (95% PCI) |
|-------------------------|-------------------------|-------------------------|
| Vina                    | 94.3 (84.2–99.4)        | 70.6 (44.6–91.3)         |
| Mbere                   | 77.2 (50.7–96.5)        | 69.3 (42.0–91.0)         |
| Djerem                  | 57.8 (29.0–84.6)        | 73.1 (51.4–90.3)         |
| Mayo Banyo              | 76.3 (52.8–95.0)        | 92.0 (72.8–99.8)         |
| Faro and Deo            | 68.1 (42.9–90.4)        | 53.1 (5.2–71.4)          |
| Overall                 | 84.0 (75.1–92.2)        | 74.6 (62.7–85.1)         |

*FMD, foot-and-mouth disease; PCI, posterior credibility interval.
Sensitivity and Specificity of Photograph Identification

Compared with sensitivity for NSP antibody testing, sensitivity was higher for herdsmen recognition of FMD lesions in 1 photograph but specificity was lower for reporting of FMD in the previous year. The sensitivities and specificities were 90.0% (95% PCI 80.4%–97.3%) and 69.5% (95% PCI 54.3%–83.4%) for those able to identify a photograph of FMD compared with 63.5% (95% PCI 44.0%–90.9%) and 83.2% (95% PCI 64.0%–96.0%) for those who could not.

Discussion

With regard to estimating herd prevalence of FMD, herdsmen performed as well as laboratory-based VN testing. Estimates of prevalence in the previous 2 years were 78.2% (95% CI 72.1%–84.3%) according to herdsmen’s reports and 80.3% (95% CI 75.0%–85.6%) according to VN test results. Sensitivities of estimates for prevalence in the previous 2 years were 95.7% (95% PCI 88.7%–99.8%) and 95.2% (95% PCI 89.6%–99.1%) and specificities were 60.0% (95% PCI 44.3%–77.5%) and 59.9% (95% PCI 45.6%–77.2%), for herdsmen’s reports and VN test results, respectively. These estimates were derived by restricting the age of cattle to <2 years and by using a no–gold standard Bayesian model (model to assess diagnostic test performance in the absence of a perfect reference test) to estimate sensitivity and specificity.

In addition to validating estimates of FMD prevalence in the previous 2 years, we also attempted to validate farmer reporting for the previous year by taking a different approach. The rationale behind using tests that detect antibodies against NSP was that the number of animals <1 year of age in the sample was insufficient to produce generalizable results and that NSP antibody titers fall more rapidly over time than do VN antibody titers (17,18). In an evaluation study in which we reported that the CHECKIT-ELISA performed less well than the I-ELISA and C-ELISA, we used 3 NSP ELISAs (23,25). The results of the CHECKIT-ELISA are included in the study reported here because they enable comparison with results in the only other publication in which herdsmen’s estimates of FMD are compared with serologically derived estimates (12).

The 84.0% sensitivity of herdsmen’s reports of FMD in the previous year was significantly lower than the sensitivity of I-ELISA (97.1%) and the C-ELISA (97.5%) results. The 75.1% specificity of herdsmen’s reports was within the Bayesian credibility limits of the NSP test results. There are no published population-based estimates of NSP antibody persistence. In experimental studies, NSP antibodies have been detected in cattle for 229 (31), 304 (32), 365 (33), 395 (24), and 560 (17) days after infection, at which point the studies were terminated. It is possible that persistence of NSP antibody for >1 year accounted for the significantly lower sensitivity of herdsmen’s reports compared with serum antibodies against NSP (i.e., NSP serum antibodies represented infection over the previous 2 years, but herdsmen reporting was confined to 1 year, when fewer herds would have been seropositive). However, the lower seroprevalence according to VN testing (80.3%) compared with NSP ELISA seroprevalence (60.0%–64.5%) would argue against this.

The only test previously used to validate herdsmen’s reports of FMD is the CHECKIT-ELISA (12). When we used the results of this test as a reference standard, estimates of the sensitivity of reporting by pastoral Masai and Sukuma herdsmen in Tanzania were similar to those for herdsmen in Cameroon. Overall sensitivities were 90.9% (95% CI 75.7%–98.1%) and 72.7% (95% CI 49.8%–89.3%), respectively; however, specificities were lower at 35.2% (95% CI 14.2%–61.7%) and 35.1% (95% CI 20.2%–52.5%), respectively (13). The results of this and another study (19) suggest that the CHECKIT-ELISA was not the best choice of reference standard and that herdsmen’s estimates are more reliable.

By restricting the age of cattle to 8–24 months, we focused on recent herd exposure. The lower limit was chosen to avoid misclassification associated with presence of maternal antibodies. The upper limit means that herds infected during the last 2 weeks of the 2-year period might not have had time to seroconvert, but given a random distribution of infection in these herds over the 24-month period, only 2% (2/104 weeks) of herds would have been infected during these last 2 weeks.

In recent years, use of latent class models to estimate sensitivity and specificity of multiple tests in the absence of a reference standard has become common practice (34). A critical assumption of this technique is that test results must be independent within 2 classes (35,36), especially when a 2-class latent model is used. We used 2 biologically different and independent test approaches: herdsmen reporting and VN testing. The assumption of conditional independence can be relaxed when there are >2 classes, but in our study, it was preserved even when 4 classes were compared; herdsmen reporting differed biologically from NSP ELISAs. A Bayesian approach to latent class models requires specification of prior distributions. The β (3,1) prior distributions given to NSP tests were based on previous findings. The uninformative β (1,1) prior distribution given to herdsmen reporting is recommended when using this technique. Model fit was assessed by using Gelman-Rubin plots and statistics.

This study covered 64,000 km² and 5 administrative divisions. Differences in reports of FMD prevalence were found for herdsmen ethnic groups, ownership status, and amount of cattle contact. However, the only variable for which a statistically significant difference was found was...
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ethnic group; sensitivity of reporting by Fulani herdsmen was greater than that by Mbororo herdsmen. The Fulani and Mbororo are the major pastoralist groups on the Adamawa. They have a common language and cultural heritage, but the Mbororo are largely nomadic whereas the Fulani tend to be sedentary (37). The greater sensitivity of reporting by Fulani herdsmen is perhaps surprising because the nomadic group might be expected have more cattle contact. However, watching cattle on a daily basis was not associated with increased reporting accuracy. The differences between the Fulani and Mbororo might be a chance finding, or it might reflect differences in education or cattle ownership. A transethnic class of livestock owner seems to be emerging, in which sedentary Fulani employ non-Fulani herders, and non-Fulani owners employ poorer Mbororo who have lost their own herds. However, in this study, ownership was not associated with increased reporting accuracy.

With regard to the higher proportion of Fulani than Mbororo herdsmen who were able to identify FMD lesions from photographs, it is possible that Mbororo herdsmen might have less access to education and less experience interpreting 2-dimensional images (38). It is also possible that herdsmen rarely see vesicles in the mouth or coronary band and are more familiar with salivation and lameness. Recognition of lameness would be similar for sedentary and nomadic herdsmen because both groups spend each day slowly walking their cattle over a grazing area.

The finding of higher specificity for herdsmen recognition of FMD in at least 1 photograph and lower sensitivity of FMD reporting indicates a higher probability of reporting true-negative herds and a lower probability of reporting true-positive herds. This finding might represent a systematic reporting bias associated with herdsmen concerns about admitting that they had had FMD in their herds or a chance finding associated with seeing a familiar concept (FMD) in an unfamiliar way (photograph).

These results suggest that in FMD-endemic areas, an effective FMD surveillance method might be simply asking herdsmen if they have seen FMD in their herds. This concept is intuitive because FMD is a common disease and herdsmen are familiar with it. Whether herdsman’s reports of FMD prevalence would be effective in countries where FMD is sporadic or less prevalent remains to be determined.

If our findings are generalizable to other diseases that produce visible clinical signs in other populations, herdsmen’s reports would provide a cost-effective surveillance mechanism that could extend to emerging diseases. In initial discussions, herdsman reported that “Njobo” (Fulfulde word for FMD) had changed in recent years by introducing terms such as “Zooyo” (Fulfulde word for FMD) in an unfamiliar way (photograph).

Observations in surveillance and emerging disease identification, we suggest that studies of animal disease prevalence in developing countries should include estimates of sensitivity and specificity of reporting.

Acknowledgments

We thank all the herdsman, heads of veterinary centers, and regional Ministère de l’Elevage, des Pêches et des Industries Animaux delegates who made this study possible.

This work was supported by the Wellcome Trust (WT053480). B.M. de C.B. held a Wellcome Trust Training Fellowship in Tropical Epidemiology but reports no conflict of interest. Cattle were sampled by a veterinary surgeon with the cattle owners’ consent.

Dr Morgan is a veterinarian at the University of Liverpool. His research interests include racehorse injuries, exotic and endemic diseases of farmed animals, aquatic animal health, molecular epidemiology of rotavirus, and use of machine learning in epidemiology.

References

1. French NP, Wall R, Cripps PJ, Morgan KL. Prevalence, regional distribution and control of blowfly strike in England and Wales. Vet Rec. 1992;131:337–42. http://dx.doi.org/10.1136/vr.131.15.337.
2. Cetinkaya B, Erdogan HM, Morgan KL. Prevalence, incidence and geographical distribution of Johne’s disease in cattle in England and the Welsh borders. Vet Rec. 1998;143:265–9. http://dx.doi.org/10.1136/vr.143.10.265.
3. Erdogan HM, Cetinkaya B, Green LE, Green LE, Cripps PJ, Morgan KL. Prevalence, incidence, signs and treatment of clinical listeriosis in dairy cattle in England. Vet Rec. 2001;149:289–93. http://dx.doi.org/10.1136/vr.149.10.289.
4. Bromsvoort BM, Tanya VN, Kitching RP, Nfon C, Hamman SM, Morgan KL. Foot and mouth disease and livestock husbandry practises in the Adamawa Province of Cameroon. Trop Anim Health Prod. 2003;35:491–507. http://dx.doi.org/10.1023/A:1027302525301.
5. Hermans PG, Morgan KL. Prevalence and associated risk factors of necrotic enteritis on broiler farms in the United Kingdom; a cross-sectional survey. Avian Pathol. 2007;36:43–51. http://dx.doi.org/10.1080/03079450601109991.
6. Inness CM, Morgan KL. Polo pony injuries: player-owner reported risk, perception, mitigation and risk factors. Equine Vet J. 2014 [cited 2014 Sep 29]. Epub ahead of print. http://onlinelibrary.wiley.com/doi/10.1111/evj.12298.
7. Healy AM, Morgan KL, Hannon D, Collins JD, Weavers E, Doherty ML. Postal questionnaire survey of scrapie in sheep flocks in Ireland. Vet Rec. 2004;155:493–4. http://dx.doi.org/10.1136/vr.155.16.493.
8. Nespeca R, Vaillancourt JP, Morrow WE. Validation of a poultry biosecurity survey. Prev Vet Med. 1997;31:73–86. http://dx.doi.org/10.1016/S0167-5877(96)01221-1.
9. Vanderhaeghe C, Dewulf J, Ribbens S, de Kruif A, Maes D. A cross-sectional study to collect risk factors associated with stillbirths in pig herds. Anim Reprod Sci. 2010;118:62–8. http://dx.doi.org/10.1016/j.anireprosci.2009.06.012.
10. Knight-Jones TJ, Gibbens J, Woolbridge M, Störk KD. Assessment of farm-level biosecurity measures after an outbreak of avian influenza in the United Kingdom. Transbound Emerg Dis. 2011;58:69–75. http://dx.doi.org/10.1111/j.1865-1682.2010.01183.x.
11. Kaler J, Green LE. Naming and recognition of six foot lesions of sheep using written and pictorial information: a study of 809 English sheep farmers. Prev Vet Med. 2008;83:52–64. http://dx.doi.org/10.1016/j.prevetmed.2007.06.003.

12. Catley A, Chibunda RT, Ranga E, Makungu S, Magayane FT, Magoma G, et al. Participatory diagnosis of a heat-intolerance syndrome in cattle in Tanzania and association with foot-and-mouth disease. Prev Vet Med. 2004;65:17–30. http://dx.doi.org/10.1016/j.prevetmed.2004.06.007.

13. Doher MG, Carpenter TE, Wilson WD, Gardner IA. Application and evaluation of a mailed questionnaire for an epidemiologic study of Corynebacterium pseudotuberculosis infection in horses. Prev Vet Med. 1998;35:241–53. http://dx.doi.org/10.1016/S0167-5877(98)00070-1.

14. Perry B, Sones K. Science for development. Poverty reduction through animal health. Science. 2007;315:333–4. http://dx.doi.org/10.1126/science.1138614.

15. Kitching RP. Clinical variation in foot and mouth disease: cattle. Rev Sci Tech. 2002;21:499–504.

16. de C. Bronsvoort BM, Nfon C, Hamman SM, Tanya VN, Kitching RP, Morgan KL. Risk factors for herdsmen-reported foot-and-mouth disease in the Adamawa Province of Cameroon. Prev Vet Med. 2004;66:127–39. http://dx.doi.org/10.1016/j.prevetmed.2004.09.010.

17. Silberstein E, Kaplan G, Taboga O, Dufy S, Palmes E. Foot-and-mouth disease virus-infected but not vaccinated cattle develop antibodies against recombinant 3AB1 nonstructural protein. Arch Virol. 1997;142:795–805. http://dx.doi.org/10.1007/s007050050119.

18. Brocchi E, Bergmann IE, Dekker A, Paton DJ, Sammin DJ, Greiner M, et al. Comparative evaluation of six ELISAs for the detection of antibodies to the non-structural proteins of foot-and-mouth disease virus. Vaccine. 2006;24:6966–79.

19. Lee JA, More SJ, Cotiwan BS. Problems translating a questionnaire for an epidemiologic study of Corynebacterium pseudotuberculosis infection in horses. Prev Vet Med. 1998;35:241–53. http://dx.doi.org/10.1016/S0167-5877(98)00070-1.

20. Kitching RP, Barnett PV, Donaldson AI, Mackay D. Foot-and-mouth disease. Prev Vet Med. 2005;68:19–33. http://dx.doi.org/10.1016/j.prevetmed.2005.01.006.

21. Gelman A, Rubin DB. Inference from iterative simulation using multiple sequences. Stat Sci. 1992;7:457–72. http://dx.doi.org/10.1214/ss/1177011316.

22. Fu Y, Cao Y, Sun P, Bao H, Bai X, Li P, et al. Development of a dot immunoblot method for differentiation of animals infected with foot-and-mouth disease virus from vaccinated animals using non-structural proteins expressed prokaryotically. J Virol Methods. 2011;171:234–40. http://dx.doi.org/10.1016/j.jviromet.2010.11.006.

23. Mackay DKJ, Forsyth MA, Davies PR, Berlinzani A, Belscham GJ, Flint M, et al. Differentiating infection from vaccination in foot-and-mouth disease using a panel of recombinant, non-structural proteins in ELISA. Vaccine. 1998;16:446–59.

24. Lubroth J, Brown F. Identification of native foot-and-mouth disease virus non-structural protein 2C as a serological indicator to differentiate infected from vaccinated livestock. Res Vet Sci. 1995;59:70–8. http://dx.doi.org/10.1016/0034-5288(95)90034-9.

25. Bronsvoort BMC, Sørensen KJ, Anderson J, Corteyn A, Tanya VN, Kitching RP, et al. A comparison of two 3ABC enzyme-linked immunosorbent assays in a cattle population with endemic, multiple-serotype foot-and-mouth disease. J Clin Microbiol. 2004;42:2108–14. http://dx.doi.org/10.1128/JCM.42.5.2108-2114.2004.

26. Hui SL, Walter S. Estimating the error rates of diagnostic tests. Biometrics. 1980;36:167–71. http://dx.doi.org/10.2307/2530508.

27. Ene C, Georgiadis MP, Johnson WO. Estimation of sensitivity and specificity of diagnostic tests and disease prevalence when the true disease state is unknown. Prev Vet Med. 2000;45:61–81. http://dx.doi.org/10.1016/S0167-5877(00)00117-3.

28. Johnson WO, Gastwirth JL, Pearson LM. Screening without a gold standard: the Hui–Walter paradigm revisited. Am J Epidemiol. 2001;153:921–4. http://dx.doi.org/10.1093/aje/k153.9.921.

29. Toft N, Jørgensen E, Højsgaard S. Diagnosing diagnostic tests: evaluating the assumptions underlying the estimation of sensitivity and specificity in the absence of a gold standard. Prev Vet Med. 2005;68:19–33. http://dx.doi.org/10.1016/j.prevetmed.2005.01.006.

30. Gelman A, Rubin DB. Inference from iterative simulation using multiple sequences. Stat Sci. 1992;7:457–72. http://dx.doi.org/10.1214/ss/1177011316.

31. Fu Y, Cao Y, Sun P, Bao H, Bai X, Li P, et al. Development of a dot immunoblot method for differentiation of animals infected with foot-and-mouth disease virus from vaccinated animals using non-structural proteins expressed prokaryotically. J Virol Methods. 2011;171:234–40. http://dx.doi.org/10.1016/j.jviromet.2010.11.006.

32. Mackay DKJ, Forsyth MA, Davies PR, Berlinzani A, Belscham GJ, Flint M, et al. Differentiating infection from vaccination in foot-and-mouth disease using a panel of recombinant, non-structural proteins in ELISA. Vaccine. 1998;16:446–59.

33. Lubroth J, Brown F. Identification of native foot-and-mouth disease virus non-structural protein 2C as a serological indicator to differentiate infected from vaccinated livestock. Res Vet Sci. 1995;59:70–8. http://dx.doi.org/10.1016/0034-5288(95)90034-9.

34. van Smeden M, Naaktgeboren CA, Reitsma JB, Moons KG, de Groot JA. Latent class models in diagnostic studies when there is no reference standard—a systematic review. Am J Epidemiol. 2014;179:423–31. http://dx.doi.org/10.1093/aje/kwt286.

35. Torrance-Rynard VL, Walter SD. Effects of dependent errors in the assessment of diagnostic test performance. Stat Med. 1997;16:2157–75. http://dx.doi.org/10.1002/(SICI)1097-0258(19971015)16:19<2157::AID-SIM653>3.0.CO;2-X.

36. Spencer BD. When do latent class models overstate accuracy for diagnostic and other classifiers in the absence of a gold standard? Biometrics. 2012;68:559–66. http://dx.doi.org/10.1111/j.1541-0420.2011.01694.x.

37. Frantz C. Are the Mbooro’en boring and are the Fulani finished? In: Eguchi PK, Azarya V, editors. Unity and diversity. Senri ethnological studies 35. Osaka (Japan): National Museum of Ethnography; 1993. p. 11–34.

38. Deregoski JB. What about pictures? Behav Brain Sci. 1993;16:757–61. http://dx.doi.org/10.1017/S0140525X00032751.

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