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Epidemiological analysis of an outbreak of foot-and-mouth disease (serotype SAT2) on a large dairy farm in Kenya using regular vaccination

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ABSTRACT

During August–September 2012, an outbreak of Foot-and-mouth Disease (FMD) due to serotype Southern African Territories-2 (SAT2) occurred on a large, extensively grazed dairy farm in Nakuru County, Kenya. Over 29 days, 400/644 (62.1%) cattle were recorded as displaying clinical signs consistent with FMD. Out of the 18 management groups present, 17 had clinical cases (weighted mean incidence rate 3.5 per 100 cattle-days, 95% CI 2.4, 5.1; range 0.064–10.9). Transmission may have been encouraged when an infected group was moved to a designated isolation paddock. A four to five day minimum incubation period was apparent in five groups for which a point source exposure was evident. Further transmission was associated with the movement of individual animals incubating infection, use of a common dip and milking parlour, and grazing of susceptible groups in paddocks neighbouring to infectious cases. Animals over 18 months old appeared to be at highest risk of disease possibly due to milder clinical signs seen among younger animals resulting in reduced transmission or cases not being recorded. Cows with a breeding pedigree containing a greater proportion of zebu appeared to be at lower risk of disease. The outbreak occurred despite regular vaccination (three times per year) last performed approximately three months before the index case. Incidence risk by the lifetime number of doses received indicated limited or no vaccine effectiveness against clinical disease. Reasons for poor vaccine effectiveness are discussed with antigenic diversity of the SAT2 serotype and poor match between the field and vaccine strain as a likely explanation. Detailed field-derived epidemiological data based on individual animals are rarely presented in the literature for FMD, particularly in East-Africa and with the SAT2 serotype. This study provides a detailed account and therefore provides a greater understanding of FMD outbreaks in this setting. Additionally, this is the first study to provide field-derived evidence of poor vaccine effectiveness using a SAT2 vaccine. Further field-based measures of vaccine effectiveness in line with evaluation of human vaccines are needed to inform FMD control policy which has previously relied heavily upon experimental data and anecdotal experience.

1. Introduction

Foot-and-mouth disease (FMD) is a highly contagious infectious disease of cloven-hooved animals caused by a Picornavirus of the genus Aphthovirus. Seven distinct serotypes with limited immunological cross protection exist, all of which are known to be highly transmissible and with devastating impacts when introduced into FMD-free countries. Transmission of FMD virus (FMDV) occurs mostly by direct contact or aerosol droplets although

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indirect transmission through animal products, fomites and wind is also possible (Alexandersen et al., 2003). Different viral strains may differ in terms of excretion levels, virulence and transmissibility (Alexandersen et al., 2003).

In recent years, outbreaks have been described in several previously FMD-free countries including the UK (Gibbens et al., 2001; Gibbens and Wilesmith, 2002), the Netherlands (Bouma et al., 2003), Japan (Muroga et al., 2012) and South Korea (Park et al., 2013). These descriptions and subsequent risk factor studies have focussed primarily on farm-to-farm level transmission, since control policies have emphasised preventing the virus moving to non-infected holdings (Wilesmith et al., 2003; Ellis-Iversen et al., 2011; Muroga et al., 2013). In endemic countries like those in sub-Saharan Africa, studies of FMD have tended to focus on genetic sequencing with phylogenetic tree construction (Sahle et al., 2007; Balinda et al., 2010; Sangula et al., 2010b; Wekesa et al., 2013), ecological studies on spatiotemporal distribution of reported outbreaks (Ayelet et al., 2012; Allepuz et al., 2013), seroprevalence (Bayissa et al., 2011; Kibore et al., 2013), and the role of wildlife (Caron et al., 2013).

In both FMD-free and endemic settings, few field data are available at the individual animal level. In "FMD-free" settings, culling is likely to begin immediately, preventing the observation of all cases and related data collection. Data are limited from endemic settings due to a combination of under-reporting, lack of resources and poor farm records. Hutber and Kitching (2000) described the temporospatial spread of FMD due to serotype O between livestock groups on a large-scale dairy farm in Saudi Arabia. This analysis indicated that physical barriers between pens slowed transmission and that direct contact was the main reason for spread. In Thailand, an outbreak of FMD serotype A on two related dairy units also indicated the importance of direct animal contact, with virus not spreading to susceptible cattle 20 metres away from an infected group (Gleeson et al., 1995).

Much of our knowledge on virus transmission has been based upon animal experiments (Orsel et al., 2007, 2009; Mardones et al., 2010; Charleston et al., 2011). These experiments cannot fully account for the heterogeneity of conditions in the field. Additionally, due to high cost, a small number of animals are often used leading to large degrees of statistical uncertainty (Alexandersen et al., 2003). Caution should be taken when extrapolating experimental results to mathematical models at a local, national or wider regional level (*e.g.* East Africa). There is therefore a need for data from real outbreaks to be reported to increase our understanding of FMDV behaviour in a variety of field settings.

Data are particularly lacking for the field evaluation of vaccines. The OIE-approved test for vaccine potency involves intradermolingual challenge of immunologically naive cattle after receiving varying doses of vaccine of the homologous strain (OIE, 2009). Subsequent disease monitoring allows the calculation of a dose that protects 50% of recipients (PD_{50}). A PD_{50} value over 3.0 is considered acceptable for use in a routine prophylactic setting though a value over 6.0 is preferred (OIE, 2009). Low repeatability and low reproducibility of this test has been reported and large confidence intervals exist due to small numbers of animals used (Goris et al., 2007; Jamal et al., 2008). Various alternative approaches have been advocated, based primarily on serological correlates (Barnett et al., 2003; Goris et al., 2008). In the field, there are many determinants of vaccine effectiveness in addition to potency, including vaccine coverage, cold chain quality and vaccination schedules. *In vitro* vaccine matching tests based on the reaction of serum from vaccinated animals to field and homologous vaccine strains provides an "*r*-value" (r_1) that indicates antigenic similarity and expected protection but does not necessarily correlate with field performance because of the many other factors that can limit vaccine effectiveness (Paton et al., 2005). For example a study from Thailand reported disease among animals that had been vaccinated 2–3 months before despite a r_1 value of 0.61 (Gleeson et al., 1995), a value that indicates a close relationship between the field and vaccine strains and expected cross-protection (Paton et al., 2005). Therefore detailed evaluation of FMD vaccines through collection and analysis of field data is essential to understand performance and limiting factors. The latter will help inform policy on FMD control using vaccination which is particularly important in regions committed to the Progressive Control Pathway (PCP) (Sumption, 2012).

Although field effectiveness studies are an essential part of ongoing evaluation of human vaccines, they are rarely conducted for veterinary vaccines, including FMD. In Israel, an outbreak on a feedlot and neighbouring dairy farm was analysed. Comparison of morbidity estimates and non-structural protein (NSP) seropositivity of groups with different vaccine histories revealed that despite a good vaccine match ($r_1 = 0.37$ compared to the recommended >0.3 for neutralising vaccine matching tests) and potency ($PD_{50} = >6.0$): (a) cattle were not protected from infection seven months post vaccination regardless of the lifetime number of doses received; (b) two doses of vaccine with the second dose three months before challenge did not provide protection from infection or clinical disease and (c) vaccination two weeks prior to the outbreak with one dose of vaccine was sufficient to provide protection from clinical disease (Elnekave et al., 2013). In Turkey, post-outbreak investigations among smallholders revealed poor effectiveness of the Asia-1 Shamir vaccine consistent with a poor vaccine match. Higher vaccine effectiveness estimates of 69% and 63% were calculated for protection from disease and infection, respectively, using the alternative Sindh-08 vaccine strain (Knight-Jones et al., 2014). Both of these studies provided information which would not have been possible to obtain through experimental studies, and both have important implications for vaccine policy.

The objectives of this study were to conduct a detailed descriptive analysis of an FMD outbreak using individual animal data in an endemic setting and to quantify risk indicators for disease including an assessment of vaccine performance. The broader aim is to use field-derived data to inform FMD control at the national and East Africa regional level in particular where vaccination is used and indicate areas for further evaluation. The analysis of this outbreak will also provide a background for further studies on FMD impact during the same outbreak.

2. Materials and methods

2.1. Farm background

The outbreak occurred at a 1600 hectare mixed arable and large-scale commercial cattle dairy farm located in Rongai subcounty of Nakuru County. An estimated 25% of the total farm area was used for livestock. Several residential properties and other businesses unrelated to the dairy herd were present on the farm with around 150 employees coming onto the farm each day. Of these, approximately 25 people had direct contact with livestock. Apart from segregation from neighbouring farms, the presence of a perimeter fence, and a policy of not purchasing replacement stock, there were no specific biosecurity measures in place. Dairy farm income was mainly through milk sales and selling in-calf or freshly calved heifers to other dairy farms. Milk was also purchased from local small-holders for onward sale to a dairy.

2.2. Study population

Numbers of FMD susceptible livestock kept on the farm were approximately 600 cattle, 100 sheep and 300 goats. Small