The Veterinary Journal 292 (2023) 105950

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

Implementation of biosecurity on equestrian premises: A narrative overview

C.R. Crew [a,b], M.L. Brennan [c], J.L. Ireland [d,*]

[a] Department of Health and Social Care, 39 Victoria Street, London SW1H 0EU, UK
[b] The Royal Veterinary College, Hawkshead Lane, Hatfield, Hertfordshire AL9 7TA, UK
[c] School of Veterinary Medicine and Science, University of Nottingham, Sutton Bonington Campus, Leicestershire LE12 5RD, UK
[d] Institute of Infection, Veterinary and Ecological Sciences, Faculty of Health and Life Sciences, The University of Liverpool, Leahurst Campus, Neston, Cheshire CH64 7TE, UK

ARTICLE INFO

Keywords:
Equine
Infection control
Quarantine
Transmission
Vaccination

ABSTRACT

Biosecurity measures are designed to prevent the introduction and spread of pathogens, and play a vital role in the equine industry, controlling endemic diseases and reducing the threat of exotic disease incursion. Equestrian premises differ with respect to disease risks, biosecurity requirements and available facilities. This narrative review summarises reported frequency of implementation for selected biosecurity measures, as well as evidence relating to potential barriers to implementation of biosecurity on equestrian premises. Possible opportunities for improvement in the adoption of equine biosecurity measures are also discussed.

Introduction

Biosecurity encompasses a range of hygiene and management measures, designed to reduce the introduction of infectious agents and to control their spread within populations or facilities (Morley, 2002). Biosecurity principles revolve around the assessment of risk and potential consequences of pathogen exposure or transmission (Wenzel and Nusbaum, 2007). The majority of biosecurity measures are directed towards non-specific disease threats rather than focused towards a particular pathogen and biosecurity is considered good everyday practice to avoid significant impacts when disease incursions occur.

Equine infectious diseases, including globally endemic diseases caused by pathogens such as *Streptococcus equi subspecies equi* (*S. equi*; strangles), equine influenza (EI) and equine herpes virus (EHV), represent a major welfare concern and result in considerable financial losses, both for owners and the wider industry (Smyth et al., 2011). In the 2007 Australian EI outbreak, the average cost of veterinary treatment was calculated at AU$969[1] per horse, and total household and business losses were estimated at A$100.3 million (Smyth et al., 2011). Furthermore, equine infectious disease can have considerable psychological impact on horse owners and other members of the equine industry (Taylor et al., 2008).

Biosecurity is critical to controlling endemic infectious disease and mitigating the threat of incursion of exotic equine infectious diseases. However, there are a number of challenges associated with implementing effective biosecurity on equestrian premises. Available facilities and use of biosecurity measures are both inconsistent between different premises and are frequently deficient (Rogers and Cogger, 2010; Rosanowski et al., 2012; USDA, 2018; Crew, 2021). Lack of biosecurity was ranked as the highest priority welfare issue affecting the United Kingdom (UK) equine population by a panel of animal welfare experts (Rioja-Lang et al., 2020). In order to identify areas for improvement, and to inform effective strategies for improving equine biosecurity, an understanding of current biosecurity implementation and the factors that influence it is required.

This narrative review details the frequency with which common biosecurity measures are implemented on equestrian premises, alongside factors related to uptake of these measures and potential barriers. Drawing on infection control research in livestock farming and human health care, areas offering potential opportunities to improve equine biosecurity are identified.

Biosecurity measures

Biosecurity recommendations for equestrian premises encompass both bioexclusion and biocontainment (Johnson and Duggan, 2012;

* Corresponding author.
E-mail address: Joanne.Ireland@liverpool.ac.uk (J.L. Ireland).

[1] AU$1 = Approximately £ 0.57, €0.64, US$0.69 at 11 January 2023

https://doi.org/10.1016/j.tvjl.2023.105950
Received 1 November 2021; Received in revised form 5 January 2023; Accepted 11 January 2023
Available online 13 January 2023

Ivens, 2015). Bioexclusion comprises risk reduction strategies that aim to prevent pathogen entry, and thereby introduction of infectious disease, to the premises. Examples of bioexclusion measures implemented on equestrian premises include; quarantine of new arrivals or returning resident equids, infection control precautions for visitors and avoidance of contact with other animals (USDA, 2016). Biocontainment measures focus on limiting pathogen transmission within the resident population, and preventing onward spread from an infected population, for example, isolation of equids suspected or confirmed as having a contagious disease (USDA, 2016). Many biosecurity measures contribute to both bioexclusion and biocontainment, such as maintenance of good hygiene (including hand hygiene, use of personal protective equipment [PPE] and disinfection of equipment or vehicles), and vaccination against specific pathogens (USDA, 2016). The following sections summarise published data on the prevalence of implementation of commonly recommended bioexclusion and biocontainment measures.

Protocols for newly arriving horses

Newly introduced equids pose a risk for introduction of infectious disease, and bioexclusion measures implemented for new arrivals are intended to reduce this risk. Recommendations for newly arriving horses include inspection for signs of clinical disease prior to entering the premises, quarantine on arrival, daily temperature checks during quarantine and ensuring up-to-date equine influenza vaccination (Johnson and Duggan, 2012; Ivens, 2015). The most recent National Animal Health Monitoring System (NAHMS) study obtained survey data from 1920 American properties with at least five resident equids (USDA, 2016). For premises that had received new resident equids in the preceding year, the most frequently reported health requirements for these animals were testing for equine infectious anaemia (EIA; 56%), anthelmintic treatment (50%) and vaccination (49%) in the last year (USDA, 2016). The high proportion of premises requiring EIA testing likely reflects compliance with American regulatory requirements for interstate movement of horses, attendance at competitions or other events, and change of ownership. In a cross-sectional study of British non-racing equestrian premises, 77% of premises owners/managers (n = 296/387) reported having a protocol for new arrivals, with passport check and anthelmintic treatment most commonly undertaken (both 57%; Hodgkinson et al., 2018b). In a survey of randomly selected non-commercial properties in New Zealand, 95% of respondents indicated that they conducted at least one biosecurity measure for new horses (Rosanowski et al., 2012). However, 18% of respondents (n = 108/595) reported that health checks were not performed for horses arriving on their premises, and 18% (n = 105/598) reported that historical information, including medical, vaccination and anthelmintic history and the horse's previous location, was not obtained (Rosanowski et al., 2012). The authors concluded that few surveyed premises undertook biosecurity measures that would protect against infectious disease (Rosanowski et al., 2012). Collectively, these studies demonstrate that a considerable proportion of equestrian premises do not implement any measures to reduce the infectious disease risk posed by introduction of new horses, and even where some form of protocol exists, it may not be sufficient to prevent pathogen transmission.

Quarantine

Quarantine is an important measure for reducing the risk of pathogen introduction to the resident herd. Quarantining newly arriving horses has been demonstrated to be effective at preventing the spread of EI (Nishiura and Satou, 2010; Gildea et al., 2011), yet is undertaken relatively infrequently. In three cross-sectional studies, utilising different questionnaire-based methodologies, low frequency of quarantine implementation was reported across a range of premises types in New Zealand (Rogers and Cogger, 2010; Rosanowski et al., 2012, 2013). On non-commercial properties, only 31% of respondents (n = 178/572) quarantined new horses for > 4 days and 26% did not quarantine arriving horses at all (Rosanowski et al., 2012). Similarly, only 32% of interviewed Thoroughbred stud farm managers (n = 9/28) routinely quarantined stallions, and only 18% (n = 5/28) reported having quarantined an arriving mare in the week preceding the survey (Rogers and Cogger, 2010). In a further study utilising face-to-face interviews of Thoroughbred and Standardbred stud managers, only 22% routinely quarantined arriving horses (Rosanowski et al., 2013). Comparable results were obtained in the American NAHMS survey, where 37% of premises reported always requiring quarantine of new resident horses (USDA, 2016). However, only 16% of premises required quarantine for non-resident equids staying on the premises for < 30 days (USDA, 2016).

Survey data on implementation of quarantine may not provide accurate prevalence estimates for effective quarantine practices. A subset of premises included in the 2015 NAHMS study (n = 223) subsequently had a biosecurity assessment undertaken by a veterinarian and/or animal health technician (USDA, 2018). Overall, 65% of assessed premises had a separate area in which quarantine of new arrivals would be possible; however, on 17% of premises, this area allowed nose-to-nose contact between quarantined and resident equids (USDA, 2018). While 85% of premises had quarantine areas that prevented shared water sources, only 21% implemented optimal practices preventing both direct and indirect contact between quarantined and resident horses (USDA, 2018). In another American study, 50% of equestrian premises that regularly received new horses required a quarantine period for these equids; however, 19% of premises did not have a quarantine area available (Kirby et al., 2010). Validation of responses achieved by premises visits undertaken by the researchers revealed that survey responses overestimated quarantine practices (Kirby et al., 2010), highlighting that owner-reported data do not necessarily reflect biosecurity implementation in practice.

Visitor protocols

Humans play a significant role in the transmission of pathogens, particularly through fomite transmission, for example via hands, clothing or equipment (Goehring et al., 2010; Rossi et al., 2017). Consequently, visitors to equestrian premises pose a risk for introduction and/or spread of pathogens. The main function of an equestrian premises will impact on both the number and type of visitors it receives. Attendance by equine professionals is commonplace, with 79% of non-commercial premises (n = 625/791) in New Zealand reporting visit(s) from at least one professional in the previous year (Rosanowski et al., 2012). The most frequently reported visiting professionals visiting equestrian premises were farriers, veterinarians, dental technicians, and equine therapists, with farriers and riding instructors making the greatest number of visits per year (Rosanowski et al., 2012). These visitors spend time handling horses on multiple premises each day and therefore have the potential to transmit disease between premises.

To mitigate potential risks, visitor protocols for equestrian premises should include biosecurity measures that minimise opportunities for fomite transmission via vehicles, people and equipment (Johnson and Duggan, 2012; Ivens, 2015). Examples of these measures include parking vehicles away from animal areas (USDA, 2016), using the premises' own or disinfected equipment, handwashing and changing clothes/overalls (Rogers and Cogger, 2010; Rosanowski et al., 2012; USDA, 2016). There is some evidence supporting effectiveness of personal biosecurity measures taken by visitors in reducing the risk of EI transmission. In a retrospective case-control study of premises in areas affected by EI during the 2007 Australian outbreak, on multivariable analysis, use of footbaths was associated with a 73% reduction in odds of premises becoming infected (Firestone et al., 2011). However, this may be a proxy indicator for overall biosecurity standards on properties that used a footbath. Again during the Australian EI outbreak, implementation of personal biosecurity measures by visitors, including

handwashing, changing clothes and shoes prior to contacting horses, was shown to be protective (Firestone et al., 2013).

Findings from biosecurity surveys have demonstrated that it is relatively uncommon for equestrian premises to have protocols in place for visiting equine professionals. On non-commercial premises in New Zealand, only 31% of survey respondents (n = 154/495) had a visitor protocol, which most commonly comprised requesting that the professional washed their hands (19% of premises; n = 94/495; Rosanowski et al., 2012). Similarly, only 25% of surveyed premises in America requested visitors took some form of infection control precaution, with a requirement for visitors to clean and disinfect their hands reported by 20% of premises (USDA, 2016). Over half of interviewed stud managers expected visiting veterinarians to follow their own protocol, but had no knowledge of what this would include (Rosanowski et al., 2013). An awareness of the risk posed by dirty equipment was demonstrated by both commercial and non-commercial owners, with some requesting that visiting veterinarians (Rogers and Cogger, 2010) and other visitors (Rosanowski et al., 2012) either cleaned equipment or used equipment provided.

In a survey of equine veterinarians in Australia following the 2007 EI outbreak, the majority of participants considered there was little likelihood of themselves spreading infectious disease from one client's horse to another and 24% stated they did not consider themselves to present any risk of pathogen transmission (Schemann et al., 2014). Where veterinarians do not recognise potential disease risk, there is likely to be little encouragement for following recommended biosecurity measures, particularly when undertaking biosecurity is not seen to be entirely practical in everyday working life (Schemann et al., 2014).

Prevention of disease spread within equestrian premises

As a herd species, regular direct contact between horses on the same premises is largely to be expected, and this contact can allow rapid transmission between horses when infection is introduced onto the premises. Indirect contact also provides opportunities for transmission between resident horses before detection of clinical disease. Effective biocontainment includes measures preventing direct, nose-to-nose contact and indirect contact between resident horses, for example, through handwashing between horses or by avoiding equipment sharing (Johnson and Duggan, 2010).

Results of two surveys of stud farm managers in New Zealand suggest that implementation of biocontainment measures largely occurs in response to the presence of disease (Rogers and Cogger, 2010; Rosanowski et al., 2013). In the absence of disease, few studs had policies for handwashing, changing clothes, changing/cleaning shoes, or cleaning equipment between groups of horses (≤20% of surveyed stud farms in both studies; Rogers and Cogger, 2010; Rosanowski et al., 2013). Conversely, in the presence of disease, the majority of studs (≥92%) reported undertaking these measures (Rogers and Cogger, 2010; Rosanowski et al., 2013). However, stud managers demonstrated an awareness of high-risk areas for pathogen transmission, with the majority of farms regularly cleaning foaling paddocks and disinfecting stocks, regardless of disease status (Rogers and Cogger, 2010). Both of these studies utilised face-to-face interviews for data collection, therefore there may be a risk of social acceptability bias. For example, the reported prevalence of biocontainment measures when disease was present on the stud farm may overestimate the true prevalence of these measures if managers gave the answers that they considered to be most acceptable, rather than the most accurate response.

Hand hygiene

Good hand hygiene following contact with infected animals is important for reducing pathogen transmission. Premises biosecurity assessments of a sample of American equestrian premises identified that 42% had adequate hand hygiene options (hand washing with soap plus hand drying materials or hand sanitiser) available within the equine housing area, although a greater proportion of large premises (≥20 resident horses) had hand hygiene facilities compared to smaller premises (USDA, 2018). Handwashing facilities were available on 86% of non-racing British premises (n = 606/708) in a cross-sectional study (Hodgkinson et al., 2018b). However, regardless of availability, respondents reported rarely/never washing their hands prior to (59%) or after (34%) equine contact (Hodgkinson et al., 2018b).

Minimising contact between groups of horses

Segregating horses by age group is recommended as a method to reduce direct horse-to-horse contact (Johnson and Duggan, 2010). Biosecurity assessments conducted on American premises found that 75% housed horses in consistent groups or individually, separate from other individuals or groups (USDA, 2018). Despite this, 65% of these premises allowed individuals or groups of horses to share a common water source (USDA, 2018). In a postal survey of British horse owners, 14% reported that their horses were turned out in an area where contact with horses from a neighbouring premises was possible (Crew, 2021). In comparison to new horses, owners perceived returning horses as posing less risk, less frequently implementing quarantine for resident horses returning after a period off the premises (Crew, 2021). However, in addition to the risk of direct contact with potentially infectious animals at events, there is also a possible risk of disease from contact with external handlers and transportation vehicles (Mee et al., 2012), which may be overlooked by owners.

Isolation facilities

Isolation of affected equids is a vital control measure in the event of an infectious disease outbreak (Johnson and Duggan, 2010). The importance of preventing shared air space for isolation facilities to effectively control disease varies depending on the pathogen of concern. For example, maintaining a separate air space is unlikely to be required for control of pathogens spread only by oral or direct transmission but is a key consideration for pathogens capable of airborne transmission such as EI virus and EHV. A study of EI outbreaks in Ireland highlighted the importance of ensuring a separate air space when isolating horses, demonstrating that the majority of horses housed in barns became clinically affected, whereas fewer horses in stables and even fewer pasture-kept horses were affected (Gildea et al., 2011). When isolation facilities are needed and not available, delays and poorly thought through solutions may lead to inadvertent spread of infection (Gildea et al., 2011). For 21% of assessed American premises with a separate isolation area, it was located zero feet from (i.e. immediately adjacent to) resident horses and 18% had isolation areas between 1 and 30 feet from the nearest resident horse (USDA, 2018). Although the required isolation distance to prevent transmission varies considerably depending on the pathogen, where it is insufficient to prevent nose-to-nose contact or short-range airborne transmission, segregation of infectious horses may be ineffective for preventing the spread of infection. Based on simulation models, reduction of horse-to-horse contact together with vaccination appeared to be more effective for controlling EI than either intervention alone (Spence et al., 2018).

Equine influenza vaccination

While vaccination recommendations vary depending on disease risks in different countries, EI is globally endemic, and vaccination against it is recommended as part of premises biosecurity plans (Ivens, 2015). Optimal minimum vaccination rate is based on the level at which herd immunity can be achieved, according to how contagious the pathogen is (Fine et al., 2011). It has been stated that a vaccination rate of at least 75% within herds provides better disease control in EI outbreaks (Singh et al., 2018). In various studies, owner-reported prevalence of EI

vaccination ranged from 79% to 89% (Hotchkiss et al., 2007; Vilela et al., 2017; Hodgkinson et al., 2018b; Bambra et al., 2020). However, estimations of true EI vaccination based on vaccination sales and estimated number of horses suggest a much lower rate. Veterinarian compliance with datasheet vaccination schedules has been shown to be poor (Wilson et al., 2021), which may reduce vaccine effectiveness. For example, longer intervals between primary vaccinations can result in increased duration of immunity gaps, where antibody levels fall below those required for clinical protection (Cullinane et al., 2014). Vaccination alone was not sufficient to prevent the spread of EI within racing yards, with 34% of horses with an up-to-date vaccination record developing clinical signs (Gildea et al., 2020).

Limitations of data on frequency of biosecurity measures

The studies discussed above provide valuable data that demonstrates the variable and often suboptimal implementation of different biosecurity measures on equestrian premises. Many of these studies were conducted in Australasia, North America, the UK and Ireland. It is important to note that disease risks, as well as equine management practices, will affect both biosecurity requirements and practices, and can differ considerably between geographic locations. As such, findings from one country are not necessarily generalisable to other equine populations. Moreover, available evidence about equine biosecurity implementation likely represents a 'best case scenario', and the true frequency with which these measures are utilised is likely to be lower. A limitation common to many of these studies is the reliance on questionnaires to gather owner-reported data, which carries a risk of errors introduced by non-response bias, where owners with a greater interest in biosecurity are more likely to participate. It is also likely that biosecurity levels assumed from their responses actually over-estimate biosecurity in practice. Additionally, a number of the studies of horse owners in Australasia were undertaken shortly following and in relation to the 2007 Australian EI outbreak, which is likely to elicit different responses than may be expected from a population which has not recently experienced or faced imminent threat of disease.

Whilst biosecurity practices are assumed to control infectious disease, there is little evidence to quantify the effectiveness of different interventions. Certain measures are likely to be more effective at controlling disease when implemented in different situations. Subsequently, while the number of measures and frequency with which each is undertaken may be used to estimate horse owner biosecurity compliance, this may not directly translate into effectiveness at preventing pathogen spread.

Challenges and potential barriers to equine biosecurity

The equine industry has some unique features that affect both biosecurity requirements and whether or not measures are implemented. Horses are kept in a range of establishments including owners' home premises, livery yards, riding schools, rented pastures and livestock farms, and in some instances, horses may be kept at multiple locations each year (Boden et al., 2013). Horses regularly travel from their home premises, including short-term movement for ridden exercise or longer distance travel involving vehicle transport (Robin et al., 2011). In a survey of 4417 British horse owners, 59% of respondents travelled and returned home with their horse within one day (Boden et al., 2013). In a study in Ontario, 1754 movements to 553 unique locations were undertaken by 330 horses over a seven-month period (Spence et al., 2019a), representing considerable opportunities for pathogens to be brought back onto horses' home premises if no precautionary measures are taken.

Effective control of infectious disease requires knowledge of the size and spatial distribution of the at-risk population, as well as the level of contact between individuals within the population. Horse contact networks vary widely between different premises and different sectors of the equestrian industry, which has a marked effect on likely pathogen transmission in an outbreak (Milwid et al., 2019). On livestock farms, maintaining a closed herd is considered the most important biosecurity measure (Sayers et al., 2014). It is less common for equestrian premises to maintain closed herds and on premises where the function of the business relies upon regular visits by non-resident horses and clients, such as competition premises or riding schools, aiming for a closed herd is directly contradictory to business pursuits.

Horse owner compliance with biosecurity recommendations

Studies have identified considerable variation in perceptions, attitudes, motivators and barriers to biosecurity between groups of horse owners in Australasia (Rogers and Cogger, 2010; Schemann et al., 2011; Rosanowski et al., 2012; Rosanowski et al., 2013; Schemann et al., 2013a,b). Voluntary compliance with biosecurity amongst horse owners is associated with both demographic and attitudinal factors (Schemann et al., 2011). In an online survey undertaken one year after the 2007 EI outbreak, 759 Australian horse owners were asked to rate the frequency of implementation of 16 biosecurity measures on a five-point scale, from every time to never (Schemann et al., 2011). A biosecurity compliance index was calculated, with 50% of respondents classed as having high compliance, 20% medium and 30% low compliance (Schemann et al., 2011). Factors associated with low compliance included young age (16–25 years), having at least two children and having no commercial involvement with horses (Schemann et al., 2011).

Perceptions of vulnerability and risk

In human medicine, several models have been created in order to explain and predict whether or not people adopt preventive health behaviours. While these different models contain a wide variety of components, perceptions of vulnerability/susceptibility to, and risk of, the given health threat are commonly included factors. One of these models is the protection motivation theory, in which perceived vulnerability is a key behavioural determinant (Norman et al., 2005). Perceived vulnerability is measure of the degree to which an individual perceives themselves to be susceptible to contracting a contagious disease, and high perceived vulnerability is likely to improve compliance with performing protective behaviours (Norman et al., 2005). Conversely, low perceived vulnerability reduces the motivation to perform protective behaviours. Perceived vulnerability amongst horse owners and premises managers has been investigated in an Australian-based study following the 2007 EI outbreak (Schemann et al., 2013a). From a randomly selected sample of premises within restricted zones during the outbreak, 200 owners and managers were interviewed, 64% of whom had experienced at least one confirmed EI case on their premises. Overall, 31% of interviewees considered themselves invulnerable to a future EI outbreak (Schemann et al., 2013a). Factors associated with low perceived vulnerability included involvement with racing, rural premises location and a high level of perceived preparedness for a future outbreak (Schemann et al., 2013a).

Perceived risk incorporates consideration of both the probability of disease occurrence as well as the severity of negative consequences of disease (van der Pligt, 1998). In a questionnaire-based study of 164 Dutch pig farmers, risk perceptions were significant predictors for adoption of on-farm biosecurity, with self-protection (risk aversion) behaviour directly contributing to the uptake of risk management strategies (Valeeva et al., 2011). There are few similar examples of the application of health behaviour models to predict biosecurity undertaken by horse owners. In an online survey of 150 Australian horse owners, low perceived risk of Hendra virus infection was identified as a barrier to uptake of vaccination (Manyweathers et al., 2017). This risk perception appeared to be based upon owners' personal risk assessments, where a lack of fruit bats populations in their area inferred a low likelihood of disease (Manyweathers et al., 2017), suggesting that

probability of infection was the predominant consideration rather than severity of the consequences of a Hendra virus case. In a large cross-sectional study of owners on non-racing premises in Britain, 60% considered that their horse was not at risk of infectious disease on an average day, most frequently based on their horse having no/limited contact with other/unknown horses (Crew, 2021). Similarly, qualitative content analysis of data obtained in a large online questionnaire-based study identified that UK leisure horse owners often considered their horse to be at low risk of exotic diseases due to no or limited mixing with other horses (Spence et al., 2019b). On surveyed American premises, the primary reason stated for not vaccinating resident equids was little risk of disease exposure (cited by ≥51% of non-vaccinating premises for all vaccinable diseases included in the survey; USDA, 2017). It is probable that management factors influence owner perceptions of risk of disease exposure and thereby decision-making about vaccination. For example, lower levels of EI vaccination have been reported by owners whose horse(s) never left the home premises, had a lack of exposure to new horses (Bambra et al., 2020), and were not involved in competition (Koskinen, 2014; Bambra et al., 2020).

Feasibility, facilities and premises-related factors

From studies of livestock farmers, it has been reported that biosecurity measures will only be implemented if farmers consider them to be feasible and practical (Garforth et al., 2013; Toma et al., 2015). The feasibility of a measure incorporates multiple factors, including cost, time, labour, and the physical structure or layout of the premises (Gunn et al., 2008; Garforth et al., 2013; Alarcon et al., 2014). These factors also apply to feasibility on equestrian premises, and have been reported to influence biosecurity implementation. Cost has been reported as a barrier for EI (Bambra et al., 2020) and Hendra virus vaccination (Manyweathers et al., 2017). In two studies on New Zealand stud farms, surveyed managers reported that the main reasons for failing to implement quarantine protocols for new mares were lack of space to prevent horse contact and constraints on time (Rogers and Cogger, 2010; Rosanowski et al., 2013). Similarly, in a survey of non-racing premises in Britain, the greatest barrier to undertaking biosecurity measures was a lack of appropriate facilities (Hodgkinson et al., 2018a).

Several positive associations between biosecurity implementation and premises size, type and number of horse movements have been reported. It is probable that lower perceived infectious disease risk contributes to reduced levels of biosecurity on smaller premises and/or those with fewer movements. Compared to small (≤90 mares) and medium (91–199 mares) premises, larger Thoroughbred stud farms (≥200 mares) more frequently had protocols for visiting veterinarians, and where present, visitor protocols were more comprehensive on larger studs (Rogers and Cogger, 2010). Non-commercial equestrian premises smaller than 6 ha were less likely to implement biosecurity measures than larger premises (6–169 ha; Rosanowski et al., 2012). Similarly, larger premises were more likely to have biosecurity facilities (Crew, 2021), and commercial premises were more likely to have dedicated isolation/quarantine facilities (Hodgkinson et al., 2018b). A greater number of British owners on commercial premises described their horse(s) as being up-to-date with EI vaccination, compared with respondents that kept their horses at home[1]. Vaccination for EI is less frequently implemented by professional owners (including yard owners or competition riders/owners whose main income came from their involvement with horses) compared to non-professional owners (Hodgkinson et al., 2018b). Results of a large online survey demonstrated an inverse relationship between EI vaccination and the number of horses owned, with the lowest vaccination rate (66%) reported for owners of more than five horses (Bambra et al., 2020).

Horse movement from the premises has been associated with increased likelihood of having biosecurity measures for arriving horses and measures to identify clinical signs of disease in horses (Rosanowski et al., 2012). Horse movements on and off the premises have been utilised as a proxy measure for risk of exposure to disease on American properties (Traub-Dargatz et al., 2012). Premises that received visiting or new resident equids introduced within the previous 12 months were classified as high-risk, while those with no equid movements on or off the premises were classified as low-risk (Traub-Dargatz et al., 2012). Medium-risk premises were those with no new or visiting equids in the previous 12 months, where resident equids returned to the premises following contact with outside horses while away from the premises. In general, low-risk premises were less likely to implement biosecurity measures than medium and high-risk premises, with the exception of preventing contact of horses with other animals and avoiding spreading manure on horse grazing areas (Traub-Dargatz et al., 2012).

Improving biosecurity on equestrian premises

The previous sections clearly demonstrate that implementation of biosecurity measures on equestrian premises is frequently suboptimal, for a range of reasons. Research investigating barriers and motivators for protective health behaviours highlights areas where changes to veterinary communication offer potential opportunities to improve equine biosecurity.

Risk communication

Awareness of disease risk has been reported to influence both on-farm and personal biosecurity measures. For example, previous experience and current local disease status influence risk perception, with a qualitative study identifying that sheep and pig farmers were likely to undertake increased precautions where disease is reported in the local area (Garforth et al., 2013). Similarly, concern for the health and welfare of their horse(s) and a recent disease outbreak on the premises were identified as key drivers of biosecurity implementation by British owners (Hodgkinson et al., 2018a). First-hand experience of the disease or a case occurring on a nearby property were the factors respondents most frequently reported as likely to prompt them to reconsider vaccinating their horse against Hendra virus in the future (Manyweathers et al., 2017). In a qualitative study of people working within the Australian Thoroughbred breeding industry, awareness of zoonotic disease risks was a motivating factor for the use of PPE (Taylor et al., 2020). Results of these studies would suggest that when there is a known elevated risk of disease, motivating owners to follow recommended biosecurity measures is likely to be an easier task, supporting a role for effective risk communication. Increased risk communication can also have indirect beneficial effects on protective behaviours. For example, in response to initial Coronavirus (COVID-19) government restrictions in early 2020, improving biosecurity measures on equestrian premises was the second most common behaviour change of horse owners (Hockenhull et al., 2021). Since perceived risk and concern about the consequences of infectious disease are important motivating factors, improving risk communication is likely to lead to increased uptake of biosecurity measures.

Increasing veterinary involvement in equine biosecurity

Research amongst both farmers and horse owners has highlighted the vital role that veterinarians play in providing biosecurity information. Both quantitative and qualitative studies of livestock farmers have found consistent results, with the majority of surveyed farmers viewing veterinarians as the most credible and reliable source of information on disease risk management, based on trust and previous experience (Garforth et al., 2013; Sayers et al., 2013; Alarcon et al., 2014; Brennan et al., 2016). During the 2007 Australian EI outbreak, most horse owners obtained infection control information from governmental sources; however, owners who received infection control information directly from a veterinarian were more likely to believe biosecurity measures to be effective (Schemann et al., 2012). Horse owners in a UK

questionnaire-based study expressed confidence in their veterinarians' knowledge, and indicated that support from proactive veterinarians increased their confidence in implementing biosecurity measures, leading to lower perceived vulnerability to exotic diseases (Spence et al., 2019b). Although the majority of surveyed British horse owners on non-racing premises reported that greater veterinary guidance would be likely to prompt a change in their biosecurity practices, only 27% of owners reported that they had ever discussed biosecurity/infection control with their veterinarian (Hodgkinson et al., 2018a).

Findings from both livestock and equine research indicate that clients value biosecurity information from their veterinarian, but formal veterinary biosecurity assessment appears to be rarely undertaken in equine practice. In the NAHMS study, although 45% of premises had consulted their veterinarian about vaccinations in the preceding year, only 6% had their veterinarian perform some form of premises biosecurity assessment (USDA, 2016). While only 42% of British non-racing premises had some form of biosecurity plan in place (Hodgkinson et al., 2018b), writing their own biosecurity plan for everyday management and disease preparedness was considered beneficial by horse owners completing an online equine biosecurity training course (Schuft et al., 2021). This proactive approach could be strengthened by increased veterinary involvement; however a qualitative study of first opinion equine veterinarians highlighted that proactive discussions about biosecurity are rare, with biosecurity behaviours and provision of advice largely adopted in response to a disease threat (Spence et al., 2021). Forty-three percent of UK cattle veterinarians reported setting aside specific time to discuss biosecurity plans with farmers (Pritchard et al., 2015), whereas qualitative interviews with UK equine veterinarians suggested that they find it difficult to achieve this within normal client contact hours (Spence et al., 2021).

Tailored biosecurity plans

Substantial variation in stable design, layout and horse contact between and within different premises highlights the difficulties that owners may face when assessing their own biosecurity practices and needs. The personalised nature of veterinary advice has the capacity to capture complex details, such as housing layout and design, and understanding where owners may need additional veterinary assistance or work-around solutions is vital. For example, on premises without a dedicated quarantine/isolation facility, the specific stabling layout could guide the most appropriate location for effective temporary isolation. Considerable importance is placed on the ability of veterinarians to deliver advice that is relevant to the individual farmer (Garforth et al., 2013). A positive impact of tailored advice has been reported in a study of 116 beef suckler farms, where results indicated that tailored biosecurity advice packages could reduce on-farm prevalence of a number of pathogens (Cardwell et al., 2016). Although the effect of tailored biosecurity advice has not yet been formally evaluated for equestrian settings, it is likely that concentrating on premises-specific nuances would facilitate owners focusing their biosecurity efforts effectively on measures that would provide the greatest benefit. The number of resident horses, equine movements onto the premises, degree of direct and indirect contact between resident horses, implementation of quarantine measures and history of infectious disease can all be utilised to estimate infectious disease risks at a premises level (Ivens, 2015).

Conclusions

Although the frequency with which individual biosecurity measures are implemented is variable, this review highlights that overall biosecurity on equestrian premises is suboptimal. While some measures such as vaccination are reportedly performed by a majority of horse owners, overall relatively few equestrian premises routine undertake other measures that would be effective for disease prevention or control. Understanding barriers and motivators for horse owner biosecurity implementation is essential to developing effective strategies to increase the uptake of equine biosecurity recommendations. While available evidence provides some insight in to these potential factors, there is a clear need for further research and development within this area to improve understanding of factors affecting biosecurity implementation on equestrian premises.

The 2019 EI outbreak in Europe and the COVID-19 pandemic will undoubtedly have shaped horse owner risk perceptions and biosecurity behaviours. This heightened awareness of disease control provides a foundation for enhancing veterinary client communication around equine biosecurity. The considerable variability of facilities and measures undertaken on different premises highlights the requirement for personalised advice. Evidence from both farm and equine studies indicates that where following protocols proves challenging within the premises-specific setting, it is likely that owner compliance will be reduced. Assessing where there may be restrictions on biosecurity implementation due to available facilities, premises layout, or constraints on time or finances provides focus for future guidance. Targeting biosecurity recommendations specifically for different equestrian premises should aid improved uptake of any future biosecurity advice.

Conflict of interest statement

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

References

Alarcon, P., Wieland, B., Mateus, A.L.P., Dewberry, C., 2014. Pig farmers' perceptions, attitudes, influences and management of information in the decision-making process for disease control. Preventive Veterinary Medicine 116, 223–242.

Bambra, W., Daly, J.M., Kendall, N.R., Gardner, D.S., Brennan, M.L., Kydd, J.H., 2020. Equine influenza vaccination as reported by horse owners and factors influencing their decision to vaccinate or not. Preventive Veterinary Medicine 180, 105011.

Boden, L.A., Parkin, T.D.H., Yates, J., Mellor, D., Kao, R.R., 2013. An online survey of horse-owners in Great Britain. BMC Veterinary Research 9, 188.

Brennan, M.L., Wright, N., Wapenaar, W., Jarratt, S., Hobson-West, P., Richens, I.F., Kaler, J., Buchanan, H., Huxley, J.N., O'Connor, H.M., 2016. Exploring attitudes and beliefs towards implementing cattle disease prevention and control measures: A qualitative study with dairy farmers in Great Britain. Animals 6, 61.

Cardwell, J.M., Winden, Van, Beauvais, S., Mastin, A, W., De Glanville, W.A., Hardstaff, J., Booth, R.E., Fishwick, J., Pfeiffer, D.U., 2016. Assessing the impact of tailored biosecurity advice on farmer behaviour and pathogen presence in beef herds in England and Wales. In: Preventive Veterinary Medicine, 135, pp. 9–16.

Crew, C.R., 2021, Optimising equine biosecurity awareness and practices to reduce the welfare impact of infectious disease. Thesis, Doctor of Philosophy, University of London Royal Veterinary College, United Kingdom.

Cullinane, A., Gildea, S., Weldon, E., 2014. Comparison of primary vaccination regimes for equine influenza: Working towards an evidence-based regime. Equine Veterinary Journal 46, 669–673.

Fine, P., Eames, K., Heymann, D.L., 2011. 'Herd immunity': A rough guide. In: Clinical Infectious Diseases, 52, pp. 911–916.

Firestone, S.M., Schemann, K.A., Toribio, J.A.L.M.L., Ward, M.P., Dhand, N.K., 2011. A case-control study of risk factors for equine influenza spread onto horse premises during the 2007 epidemic in Australia. Preventive Veterinary Medicine 100, 53–63.

Firestone, S.M., Lewis, F.I., Schemann, K., Ward, M.P., Toribio, J.A.L.M.L., Dhand, N.K., 2013. Understanding the associations between on-farm biosecurity practice and equine influenza infection during the 2007 outbreak in Australia. Preventive Veterinary Medicine 110, 28–36.

Garforth, C.J., Bailey, A.P., Tranter, R.B., 2013. Farmers' attitudes to disease risk management in England: A comparative analysis of sheep and pig farmers. Preventive Veterinary Medicine 110, 456–466.

Gildea, S., Arkins, S., Cullinane, A., 2011. Management and environmental factors involved in equine influenza outbreaks in Ireland 2007-2010. Equine Veterinary Journal 43, 608–617.

Gildea, S., Lyons, P., Lyons, R., Gahan, J., Garvey, M., Cullinane, A., 2020. Annual booster vaccination and the risk of equine influenza to Thoroughbred racehorses. Equine Veterinary Journal 52, 509–515.

Goehring, L.S., Landolt, G.A., Morley, P.S., 2010. Detection and management of an outbreak of equine herpesvirus type 1 infection and associated neurological disease in a veterinary teaching hospital. Journal of Veterinary Internal Medicine 24, 1176–1183.

Gunn, G.J., Heffernan, C., Hall, M., McLeod, A., Hovi, M., 2008. Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries. Preventive Veterinary Medicine 84, 310–323.

Hockenhull, J., Bell, C., White, J., Rogers, S., 2021. Response of UK horse, pony and donkey owners to the early stages of the COVID-19 pandemic. Animals 11, 1215.
Hodgkinson, C.R., Slater, J., Brennan, M.L., Robin, C.A., Dyson, S., Ireland, J.L., 2018a, Attitudes towards equine biosecurity among horse owners in Great Britain. Proceedings of the 15th International Symposium on Veterinary Epidemiology and Economics, Chiang Mai, Thailand. 12th-16th November 2018.
Hodgkinson, C.R., Slater, J., Brennan, M.L., Robin, C.A., Dyson, S., Ireland, J.L., 2018b. Implementation of biosecurity on equestrian premises in Great Britain. Equine Veterinary Journal 50 (S52), 8.
Hotchkiss, J.W., Reid, S.W., Christley, R., 2007. A survey of horse owners in Great Britain regarding horses in their care. Part 1: Horse demographic characteristics and management. Equine Veterinary Journal 39, 294–300.
Ivens, P., 2015. Implementing biosecurity in an equine environment. Veterinary Times 45, 4–6.
Johnson, J., Duggan, V., 2010. Bio-security on equine holdings in Ireland. Irish Veterinary Journal 63, 244–251.
Kirby, A.T., Traub-Dargatz, J.L., Hill, A.E., Kogan, L.R., Morley, P.S., Heird, J.C., 2010. Development, application, and validation of a survey for infectious disease control practices at equine boarding facilities. Journal of the American Veterinary Medical Association 237, 1166–1172.
Koskinen, H.I., 2014. A survey of horse owner's compliance with the Finnish vaccination program. Journal of Equine Veterinary Science 34, 1114–1117.
Manyweathers, J., Field, H., Longnecker, N., Agho, K., Smith, C., Taylor, M., 2017. 'Why won't they just vaccinate' Horse owner risk perception and uptake of the Hendra virus vaccine. BMC Veterinary Research 13, 103.
Mee, J.F., Geraghty, T., O'Neill, R., More, S.J., 2012. Bioexclusion of diseases from dairy and beef farms: Risks of introducing infectious agents and risk reduction strategies. The Veterinary Journal 194, 143–150.
Milwid, R.M., O'Sullivan, T.L., Poljak, Z., Laskowski, M., Greer, A.L., 2019. Comparing the effects of non-homogenous mixing patterns on epidemiological outcomes in equine populations: A mathematical modelling study. Scientific Reports 9, 3227.
Morley, P.S., 2002. Biosecurity of veterinary practices. Veterinary Clinics of North America: Food Animal Practice 18, 133–155.
Nishiura, H., Satou, K., 2010. Potential effectiveness of public health interventions during the equine influenza outbreak in racehorse facilities in Japan, 2007. Transboundary and Emerging Diseases 57, 162–170.
Norman, P., Boer, H., Seydel, E.R., 2005. Protection motivation theory. Predicting Health Behaviour, Second edn..,. Open University Press,, Maidenhead, Berkshire, UK, pp. 81–126.
Pritchard, K., Wapenaar, W., Brennan, M.L., 2015. Cattle veterinarians' awareness and understanding of biosecurity. Veterinary Record 176, 546-546.
Rioja-Lang, F.C., Connor, M., Bacon, H., Dwyer, C.M., 2020. Determining a welfare prioritization for horses using a Delphi method. Animals 10, 647.
Robin, C.A., Wylie, C.E., Wood, J.L.N., Newton, J.R., 2011. Making use of equine population demography for disease control purposes: Preliminary observations on the difficulties of counting and locating horses in Great Britain. Equine Veterinary Journal 43, 372–375.
Rogers, C.W., Cogger, N., 2010. A cross-sectional survey of biosecurity practices on Thoroughbred stud farms in New Zealand. New Zealand Veterinary Journal 58, 64–68.
Rosanowski, S.M., Rogers, C.W., Cogger, N., Benschop, J., Stevenson, M.A., 2012. The implementation of biosecurity practices and visitor protocols on non-commercial horse properties in New Zealand. Preventive Veterinary Medicine 107, 85–94.
Rosanowski, S.M., Cogger, N., Rogers, C.W., 2013. An investigation of the movement patterns and biosecurity practices on Thoroughbred and Standardbred stud farms in New Zealand. Preventive Veterinary Medicine 108, 178–187.
Rossi, G., Smith, R.L., Pongolini, S., Bolzoni, L., 2017. Modelling farm-to-farm disease transmission through personnel movements: From visits to contacts, and back. Scientific Reports 7, 1–11.
Sayers, R.G., Sayers, G.P., Mee, J.F., Good, M., Bermingham, M.L., Grant, J., Dillon, P.G., 2013. Implementing biosecurity measures on dairy farms in Ireland. The Veterinary Journal 197, 259–267.
Sayers, R.G., Good, M., Sayers, G.P., 2014. A survey of biosecurity-related practices, opinions and communications across dairy farm veterinarians and advisors. The Veterinary Journal 200, 261–269.
Schemann, K., Taylor, M.R., Toribio, J.A.L.M.L., Dhand, N.K., 2011. Horse owners' biosecurity practices following the first equine influenza outbreak in Australia. Preventive Veterinary Medicine 102, 304–314.
Schemann, K., Firestone, S.M., Taylor, M.R., Toribio, J.A.L.M.L., Ward, M.P., Dhand, N. K., 2012. Horse owners'/managers' perceptions about effectiveness of biosecurity measures based on their experiences during the 2007 equine influenza outbreak in Australia. Preventive Veterinary Medicine 106, 97–107.
Schemann, K., Firestone, S.M., Taylor, M.R., Toribio, J.A.L.M.L., Ward, M.P., Dhand, N. K., 2013a. Perceptions of vulnerability to a future outbreak: A study of horse managers affected by the first Australian equine influenza outbreak. BMC Veterinary Research 9, 152–161.
Schemann, K., Lewis, F.I., Firestone, S.M., Ward, M.P., Toribio, J.A.L.M.L., Taylor, M.R., Dhand, N.K., 2013b. Untangling the complex inter-relationships between horse managers' perceptions of effectiveness of biosecurity practices using Bayesian graphical modelling. Preventive Veterinary Medicine 110, 37–44.
Schemann, K., Toribio, J.A.L.M.L., Taylor, M.R., Ward, M.P., Dhand, N.K., 2014. Survey of Australian equine veterinarians evaluating their biosecurity training and perceptions and opinions about the management of the 2007 equine influenza outbreak. Australian Veterinary Journal 92, 93–100.
Schuft, A., Cortus, E., Martinson, K., 2021. An online course to teach and encourage equine biosecurity practices. Journal of Equine Veterinary Science 100, 103577.
Singh, R.K., Dhama, K., Karthik, K., Khandia, R., Munjal, A., Khurana, S.K., Chakraborty, S., Malik, Y.S., Virmani, N., Singh, R., Tripathi, B.N., Munir, M., van der Kolk, J.H., 2018. A comprehensive review on equine influenza virus: Etiology, epidemiology, pathobiology, advances in developing diagnostics. vaccines, and Control Strategies Frontiers in Microbiology 9, 1941.
Smyth, G.B., Dagley, K., Tainsh, J., 2011. Insights into the economic consequences of the 2007 equine influenza outbreak in Australia. Australian Veterinary Journal 89 (S1), 151–158.
Spence, K.L., O'Sullivan, T.L., Poljak, Z., Greer, A.L., 2018. Using a computer simulation model to examine the impact of biosecurity measures during a facility-level outbreak of equine influenza. Canadian Journal of Veterinary Research 82, 89–96.
Spence, K.L., O'Sullivan, T.L., Poljak, Z., Greer, A.L., 2019a. Descriptive analysis of horse movement networks during the 2015 equestrian season in Ontario, Canada. PLoS ONE 14, 1–16.
Spence, K.L., Cardwell, J.M., Slater, J., Rosanowski, S.M., 2019b. Preliminary insight into horse owners' perceptions of, and attitudes towards, exotic diseases in the United Kingdom. BMC Veterinary Research 15, 1–9.
Spence, K.L., Rosanowski, S.M., Slater, J., Cardwell, J.M., 2021. Challenges to exotic disease preparedness in Great Britain: The frontline veterinarian's perspective. Equine Veterinary Journal 54, 563–573.
Taylor, M.R., Agho, K.E., Stevens, G.J., Raphael, B., 2008. Factors influencing psychological distress during a disease epidemic: Data from Australia's first outbreak of equine influenza. BMC Public Health 8, 347.
Taylor, K., Thomas, S., Mendez, D., Chicken, C., Carrick, J., Heller, J., Durrheim, D., 2020. 'Prevention is the biggest success': Barriers and enablers to personal biosecurity in the Thoroughbred breeding industry. Preventive Veterinary Medicine 183, 105135.
Toma, L., Low, J.C., Vosough Ahmadi, B., Matthews, L., Stott, A.W., 2015. An analysis of cattle farmers' perceptions of drivers and barriers to on-farm control of Escherichia coli O157. Epidemiology and Infection 143, 2355–2366.
Traub-Dargatz, J., Kopral, C., Wagner, B., 2012. Relationship of biosecurity practices with the use of antibiotics for the treatment of infectious disease on U.S. equine operations. Preventive Veterinary Medicine 104, 107–113.
USDA, 2016, United States Department of Agriculture. Baseline reference of equine health and management in the United States, 2015. https://www.aphis.usda.gov/animal_health/nahms/equine/downloads/equine15/Eq2015_Rept1.pdf (Accessed 11 January, 2023).
USDA, 2017, United States Department of Agriculture. Equine management and select equine health conditions in the United States, 2015. https://www.aphis.usda.gov/animal_health/nahms/equine/downloads/equine15/Eq2015_Rept3.pdf (Accessed 11 January, 2023).
USDA, 2018, United States Department of Agriculture. Biosecurity assessment of U.S. equine operations. https://www.aphis.usda.gov/animal_health/nahms/equine/downloads/equine15/Eq2015_Rept4.pdf (Accessed 11 January, 2023).
Valeeva, N.I., van Asseldonk, M.A.P.M., Backus, G.B.C., 2011. Perceived risk and strategy efficacy as motivators of risk management strategy adoption to prevent animal diseases in pig farming. Preventive Veterinary Medicine 102, 284–295.
Van Der Pligt, J., 1998. Perceived risk and vulnerability as predictors of precautionary behaviour. British Journal of Health Psychology 3, 1–14.
Vilela, A., Bedford, C., Scantlebury, C., Kirton, R., 2017, Redwings strangles survey results: Main report. https://www.redwings.org.uk/sites/default/files/Strangles%20survey%20results%20main%20report%202017%20FINAL%20small.pdf (Accessed 11 January, 2023).
Wenzel, J.G.W., Nusbaum, K.E., 2007. Veterinary expertise in biosecurity and biological risk assessment. Journal of the American Veterinary Medical Association 230, 1476–1480.
Wilson, A., Pinchbeck, G., Dean, R., McGowan, C., 2021. Equine influenza vaccination in the UK: Current practices may leave horses with suboptimal immunity. Equine Veterinary Journal 53, 1004–1014.