Title

A review of paratuberculosis in dairy herds - Part 2: On-farm control

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Abstract

Bovine paratuberculosis is a chronic infectious disease of cattle, caused by *Mycobacterium avium* subspecies *paratuberculosis* (MAP). This is the second in a two-part review of the epidemiology and control of paratuberculosis in dairy herds. Several negative production effects associated with MAP infection have been described, but perhaps the most significant concern in relation to the importance of paratuberculosis as a disease of dairy cattle is the potential link with Crohn's disease in humans. Milk is considered a potential transmission route to humans and it is recognised that pasteurisation does not necessarily eliminate the bacterium. Therefore, control must also include reduction of the levels of MAP in bulk milk supplied from dairy farms. There is little field evidence in support of specific control measures, although several studies seem to show a decreased prevalence associated with the implementation of a combined management and test-and-cull programme. Improvements in vaccination efficacy and reduced tuberculosis (TB) test interference may increase uptake of vaccination as a control option. Farmer adoption of best practice recommendations at farm level for the control of endemic diseases can be challenging. Improved understanding of farmer behaviour and decision making will help in developing improved communication strategies which may be more efficacious in affecting behavioural change on farm.

Keywords: Control; Dairy; Johne's disease; Motivation; Paratuberculosis

Introduction

Paratuberculosis is a chronic infectious disease caused by *Mycobacterium avium* subspecies *paratuberculosis* (MAP), causing chronic granulomatous enteritis resulting in production effects, diarrhoea and emaciation. Several negative production effects associated with MAP infection have been described, but perhaps the most significant concern in relation to the importance of paratuberculosis as a disease of dairy cattle is the potential link with Crohn's disease in humans. Milk is considered a potential transmission route to humans and it is recognised that pasteurisation does not necessarily eliminate the bacterium. Therefore, control must also include reduction of the levels of MAP in bulk milk supplied from dairy farms. This is the second of a two-part review of the epidemiology and control of paratuberculosis in dairy herds.

On-farm control

Control of paratuberculosis is challenging and although eradication from goat herds has been reported (Gavin et al., 2018), there are no published reports of eradication of the organism from infected cattle herds (Barkema et al., 2018). Options for control of paratuberculosis within infected herds have been necessarily ascertained through biological plausibility based on known shedding routes and age susceptibility. Owing to the long incubation of the disease and the poor sensitivity of diagnostic tests, field trials on the efficacy of these control options are lacking. Many risk factor studies have attempted to estimate the impact of various control measures on the probability of herd positivity, and/or the within-herd prevalence; however, many of these studies fail to agree with the agreed risk factors/control options for the disease (McAloon et al., 2017a). There are many reasons why this might be the case; these studies may not be sufficiently powered to overcome misclassification that occurs as a result of imperfect tests. In addition, many of these studies were cross-sectional and therefore poorly designed for inferring on causality; subject to time-delays and reverse causality; and have a low evidence weighting.

Reduced prevalence was demonstrated over time in nine US dairy herds associated with the implementation of seven control ‘actions’: segregated calving; removal of calf within 2 h; selection and hygienic collection of colostrum; feeding of pasteurised milk or milk replacer only; segregation from the adult herd; culling of strong ELISA-positive; and selection of replacement heifers from ELISA-negative cows (Collins et al., 2010). In other instances, decreased prevalence over time has been demonstrated in herds enrolled in national control programmes. A reduction in newly detected shedding animals over a 6-year period was demonstrated in 25 German dairy herds (Donat, 2016a). In Minnesota, calves born from 12 months before the introduction of a control programme were at a lower risk of infection than those born 12-24 months before the introduction of the programme in six dairy herds (Ferrouillet et al., 2009).

However, these studies contained a relatively small number of herds and no control herds, and it was not possible to evaluate individual aspects of the control programme, or to separate the effect of testing and culling from hygiene management for example. An additional difficulty in assessing the efficacy of control programmes in a field study is that to demonstrate efficacy the outcome of interest is the incidence of new MAP infections, rather than the prevalence. This requires that animals were uninfected prior to the beginning of the observation period, which can be problematic in the context of JD.

To study the impact of controls in a more economical manner, several research groups have developed infectious disease transmission models for paratuberculosis, which allow researchers to study the effect of control measures in isolation (Marcé et al., 2010). From the earliest transmission models, it was inferred that testing and culling strategies were likely to be ineffective in controlling disease and that the greatest success was found when test and cull and management control practices were combined. A US simulation found that testing and culling strategies had a comparable effect to management changes in reducing prevalence over time (Collins and Morgan, 1992), whereas a Danish study reported that test-and-cull methods had a negligible effect on prevalence and may only be useful as an incentive for farmers (Groenendaal et al., 2002). A later study reported that within-herd prevalence increased despite testing and culling, and that a reduction in prevalence could only be achieved with optimal management, whilst a greater improvement was made when test-and-culling was combined with optimal management (Kudahl et al., 2007). Similarly, a recent French modelling study has shown that calf management and test-and-cull both were required to maximize the probability of stabilizing herd status, however, reduced calf exposure was the most influential measure (Camanes et al., 2018). It should also be noted that models that evaluate specific management options may not include indirect benefits associated with the implementation of improved management that might occur such as improved biosecurity generally for example.

However, more recently, models have suggested that test-and-cull may reduce prevalence, and in many cases may be the most optimal economic management approach. For example, a 2010 study found that test-based culling intervention generally decreased prevalence over time, although it took longer than desired by producers to eliminate the endemic MAP infection from a herd (Lu et al., 2010). Similarly, the same research group, showed that risk-based culling could substantially reduce the prevalence of paratuberculosis over time, but that it could not eliminate infection in isolation (Al-Mamun et al., 2017). In terms of optimising economic return given investment in control options and effect of infection on productivity, two separate models from the US and Denmark have shown that in many cases no control was preferred, particularly in smaller herds and that test and culling was preferable to hygiene controls in most cases (Kirkeby et al., 2016; Smith et al., 2017).

Whilst the impact of testing and culling on the prevalence of MAP infection over time is not clear cut, it is likely to dramatically reduce the incidence of clinical JD on problem farms. An Irish qualitative study demonstrated that clinical JD was a considerably emotive disease, with substantial emotional stress on the farmer (McAloon et al., 2017b). Therefore, the reduction in the incidence of clinical disease on infected farms is likely to have a significant impact on both animal and farmer welfare.

Vaccination to control JD has been reviewed recently (Bastida and Juste, 2011). The first report on vaccination of cattle for MAP was in the 1920s (Vallee and Rinjard, 1926). Perhaps the greatest success has been demonstrated with the use of vaccination in control JD in sheep (Dhand et al., 2013), where early modelling studies demonstrated a cost benefit to vaccination of replacement ewe lambs (Juste and Casal, 1993). In cattle, vaccination will likely delay the onset of clinical disease, reduce the number of clinical cases and reduce shedding from infected animals (Bastida and Juste, 2011; Alonso-Hearn et al., 2012; Tewari et al., 2014). However, studies demonstrating prevention of infection are less consistent in their conclusions (Kalis et al., 2001). Nevertheless, a number of modelling studies have demonstrated that vaccination may be a more economically attractive option for farmers than a combined programme of test and cull, and management programmes (Cho et al., 2012; Lu et al., 2013), apart from situations where there is a high frequency of TB testing (Groenendaal et al., 2015).

The most problematic issue with vaccination occurs in countries with ongoing tuberculosis (TB) eradication programmes. Vaccination negatively impacts the sensitivity of the single intradermal comparative cervical tuberculin skin-test (SICCT) and reduces the specificity of currently available MAP serological diagnostics (Coad et al., 2013). However, a recent study has shown that modification of the TB skin test reagents may overcome this issue (Serrano et al., 2017). Several genomics-based approaches to the development of MAP vaccines with complementary diagnostics that do not suffer of these problems are currently underway (Barkema et al., 2018).

Many regions and nations around the globe have developed and introduced control programmes for JD. Australia, regions of the US, and Germany, Ireland, Canada, UK, Denmark and the Netherlands, represent the areas with the most developed control programmes which often include ongoing sampling and on-farm control plans covering relevant aspects of bioexclusion and biocontainment (Geraghty et al., 2014). Some programmes also include herd categorisation or assurance scores to facilitate risk-based trading. Control programmes in France and Germany are implemented on a regional/state basis (Fourichon and Guatteo, 2014; Donat, 2016a). Participation in national control programmes is generally on a voluntary basis with the exception of the Dutch programme in which participation became compulsory since 2011 (Geraghty et al., 2014). In other countries such as Japan and Norway, mandatory active surveillance for JD is conducted through sampling of herds on a regular basis. In Austria and Sweden, animals showing signs of clinical disease are required to have a test sample collected under national legislation (Khol and Baumgartner, 2012). Similarly, in Italy there is compulsory reporting of clinical cases alongside a voluntary herd classification programme based on serological screening (Arrigoni et al., 2014).

Countries adopting an on-farm control plan as part of their national programme have generally structured this component through a veterinary administered, written Risk Assessment (RA) and Management Plan (MP) based on current knowledge of MAP and JD, known risk factors, biological plausibility, and expert opinion (Kalis et al., 2004). These questionnaire-based RAs are used to highlight high-risk management area practices for dairy producers and to recommend changes in on-farm management for JD control.

Motivating change on farm

Farmer adoption of best practice recommendations at farm level for the control of endemic diseases can be challenging (Ritter et al., 2017). A person's behaviour, and decision to adopt a given recommendation to change their behaviour, is influenced by a complex set of relationships between knowledge, attitudes, perceptions, motivation, external communication, and other social factors (Rosenstock, 1974; Ajzen, 1991; Leeuwis and van den Ban, 2004; Boxelaar and Paine, 2005; Rehman et al., 2007). A range of sociological and psychological tools and models have been developed to understand and influence decision making and behaviour on farm. Several have been extrapolated from human medicine, for example the Health Belief Model (Janz and Becker, 1984) or the Theory of Planned Behaviour (Ajzen, 1991). These models describe the process of how, based on a foundation of knowledge, a range of factors influence an individual's attitude and perception of a particular behaviour and their intention to perform that behaviour.

An individual's knowledge with respect to a given topic or issue provides the foundation for their behaviours (Pratt and Bowman, 2008; Garforth et al., 2013), yet producers do not make on-farm decisions purely based on scientific merit and logic (Kuiper et al., 2005; Pratt and Bowman, 2008; Ellis-Iversen et al., 2010; Jansen et al., 2010; Garforth, 2011; Kristensen and Jakobsen, 2011; Lam et al., 2011; Garforth et al., 2013). For example, Kuiper et al. (2005) reported that a lack of general knowledge about mastitis among Dutch dairy farmers was not a key factor influencing the adoption of preventative practices. Rather, external triggers (e.g. sanctions, incentives), internal beliefs and perceptions were the key factors influencing producer behaviour. Whilst an understanding of JD and JD control measures is important for producers, knowledge alone is likely insufficient to influence behaviour (Ritter et al., 2017).

Attitude and perception are key factors influencing behavioural change (Leeuwis and van den Ban, 2004; Garforth, 2011). Leeuwis and van den Ban (2004) provided a particularly comprehensive model that describes the basic variables relevant to understanding a producer's behaviour, which are: evaluative frame of reference, perceived environmental effectiveness, perceived self-efficacy, and social relationships and perceived social pressure.

In the context of JD, the evaluative frame of reference corresponds to the factors that a producer considers when rationalising a behavioural change. Producers will consider their perception of the consequences of the JD control practices they are asked to implement (e.g. labour, time investment, impact, required inputs, etc.) (Ritter et al., 2016). They will also consider their perceptions of the risk of JD to their farm and livelihood, and the likelihood that changing their behaviour will positively impact JD control. These perceptions will be based on personal and professional goals and aspirations, physical resources (i.e. time, money, infrastructure), personal values, and what they believe are the social norms with respect to the practice.

A producer's perception of environmental effectiveness refers to whether they believe that their existing socio-economic environment can support the behaviour(s) they are being asked to undertake. For example, a producer considering on-farm changes for JD will consider: the availability of support from their veterinarian and fellow farmers (Ritter et al., 2015), availability and reliability of physical and organizational resources (e.g. colostrum and/or milk replacer), and market prices (e.g. milk price, cow replacement price).

Perceived self-efficacy refers to a person's confidence in his or her own ability to perform a given behaviour. More specifically, producers will consider their ability to obtain and mobilize resources (i.e. money and labour), their own personal skills and competence, and their ability to control or manage the risks that may arise from adopting the behaviour.

Lastly, producers will consider their social relationships and perception about the social pressures being put on them to perform a behaviour. They consider what the expectations are of them from other sources (e.g. friends, family, peers, organizations, etc.), and the resources, penalties, and incentives that exist to persuade them to make the change. Individuals are then likely to place a value on these perceptions that will be weighted based on their personal feelings, relationships, and experiences with these sources. Therefore, for JD control, a producer is likely to consider what their fellow producers, veterinarians, industry organizations, and extension specialists expect of them with respect to JD control. The value they place on these perceptions will then ultimately determine how they respond.

An individual's motivation is another important factor influencing behaviour. A producer can be motivated externally or internally (Leeuwis and van den Ban, 2004). External, or extrinsic, motivation relates to when a behaviour or activity is performed in order to obtain a separable outcome (e.g. money) (Ryan and Deci, 2000). While incentive and reward-based systems are often used to externally motivate voluntary behaviour change (Nightingale et al., 2008), extrinsic motivation can also relate to the performance of a behaviour to avoid a separable outcome (e.g. financial fine or penalty). In the case of penalties, externally motivated behaviour change is focused on compulsory behaviours (Lam et al., 2011). Interestingly, research into the impact of external motivation suggests that penalty systems related to milk quality (i.e. penalties applied for milk with high bulk tank somatic cell counts) are more effective than premium systems (i.e. incentives for milk with low bulk tank somatic cell counts) (Valeeva et al., 2007). However, for JD, these structured penalties are not in place and the potential benefits of change are not immediately obvious to the farmer. In addition, these penalty systems are generally unsustainable, as the behaviour will likely only last while the coercion, either positive or negative, exists (van Woerkum et al., 1999).

Conversely, internal, or intrinsic, motivation refers to performing a behaviour purely out of interest or for enjoyment (Ryan and Deci, 2000). Lam et al. (2011) suggested that producers can be internally motivated through reasoned opinions and the use of numerous communication techniques (e.g. articles in magazines, study groups, discussions between producers and veterinarians), which target a producer's attitudes and perceptions. Very little research has been conducted to investigate the factors that motivate dairy producers to adopt on-farm changes to address JD. While numerous studies suggest that the economic losses associated with JD will motivate producers (Raizman et al., 2009; Benjamin et al., 2010;

Bhattarai et al., 2013), little is known about other motivating factors for producers to change. Additional investigations are needed to highlight the key motivating factors, which can then be addressed to internally motivate producers to change their behaviour.

Whilst clinical JD may be an emotive and distressing condition for farmers to deal with (McAloon et al., 2017b), herds where there is a high incidence of clinical disease represent a minority of infected herds. This may perhaps further lessen the likelihood of farmers widely realizing benefits from implementing on-farm changes for prevention and control. However, it is important to note that more recent research has explored the use of different tools and methods, based on the socio-psychological work previously referred to, for motivating adoption of control measures for paratuberculosis. Trier et al. (2012), Groenendaal et al. (2003), Kingham and Links (2012) and Roche et al. (2015) have reported the implementation of small, producer-group-based approaches to JD extension, which have been reported to be effective in improving adoption of on-farm recommendations for JD control in Danish and Dutch dairy herds, Australian sheep flocks, and Canadian dairy herds, respectively.

Whilst there is a growing body of literature on factors resulting in preventative management changes for MAP infection, there is little on the use of vaccination. A recent UK qualitative study investigating the general use of vaccination on dairy farms found, that veterinarians were embedded into decision making around vaccination at farm level, however, farmers were likely to vaccinate only if they had a perceived problem (Richens et al., 2015), suggesting that vaccination might be used when there is an unacceptable incidence of clinical disease.

It is well established that economic arguments are generally poor at influencing on-farm change (Vanclay, 2004) and it has been shown that the desire of being a good farmer or job satisfaction can be important motivators to improve disease prevention and control (Ritter et al., 2017). As a result, our communication approaches used to motivate on-farm change must be increasingly tailored to the mindset of the farmers (Barkema et al., 2018) and embrace multidisciplinary methods, particularly those coming from the social and socio-psychological fields.

Conclusions

Much has been learned about the epidemiology of paratuberculosis in dairy herds. Continued efforts to determine the most important factors for transmission will aid in prioritisation of efforts for control on farm. With improved knowledge and confidence in the likely impact of various control measures, further efforts to optimally tailor communication strategies will likely increase their uptake.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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