

REVIEW ARTICLE

Contamination of food products with *Mycobacterium avium paratuberculosis*: a systematic review

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Summary

Although a causal link between *Mycobacterium avium* subspecies *paratuberculosis* (MAP) and Crohn's disease has not been proved, previous studies suggest that the potential routes of human exposure to MAP should be investigated. We conducted a systematic review of literature concerning the likelihood of contamination of food products with MAP and the likely changes in the quantity of MAP in dairy and meat products along their respective production chains. Relevant data were extracted from 65 research papers and synthesized qualitatively. Although estimates of the prevalence of Johne's disease are scarce, particularly for non-dairy herds, the available data suggest that the likelihood of contamination of raw milk with MAP in most studied regions is substantial. The presence of MAP in raw and pasteurized milk has been the subject of several studies which show that pasteurized milk is not always MAP-free and that the effectiveness of pasteurization in inactivating MAP depends on the initial concentration of the agent in raw milk. The most recent studies indicated that beef can be contaminated with MAP via dissemination of the pathogen in the tissues of infected animals. Currently available data suggests that the likelihood of dairy and meat products being contaminated with MAP on retail sale should not be ignored.

Introduction

Paratuberculosis (Johne's disease, JD) is a chronic disease of ruminants caused by *Mycobacterium avium* subspecies *paratuberculosis* (Collins 1997). Although infection mainly occurs at early stages of life the clinical symptoms appear after 2–5 years (Whitlock and Buergelt 1996). Infection occurs mainly through ingestion of MAP contaminated colostrum, milk and other contaminated feedstuffs (Stabel 1998). Intrauterine transmission of MAP may occur especially in clinically infected cases (Lambeth *et al.* 2004). Clinically and subclinically infected animals shed MAP in their faeces and milk and consequently contaminate the environment and spread the infection (Sweeney *et al.* 1992; Cocito *et al.* 1994).

Milk could be contaminated with MAP by either direct shedding of the micro-organisms or faecal contamination during or after milking (Grant *et al.* 2002). MAP has been detected in raw and pasteurized milk from cows, sheep

and goats and cheeses on retail sale in different countries. This indicates that humans may be potentially exposed to MAP through consumption of dairy products (Grant 2003; Ayele *et al.* 2005; Ikonomopoulos *et al.* 2005). Although MAP has not been isolated from meat products (Grant 2006), such products may be contaminated as a result of the dissemination of MAP within the tissues of systemically infected animals. MAP has been isolated from the gut, liver and lymph nodes of these animals (Hines *et al.* 1987; Rossiter and Henning 2001). More recently, MAP DNA has been recovered from surface-swabs collected from beef carcasses after skinning and dressing (Meadus *et al.* 2008).

MAP has been suggested as a possible cause of Crohn's disease (CD), a chronic intestinal inflammation of humans (Chamberlin *et al.* 2001; Hermon-Taylor and Bull 2002). Although this link has not been proved, there is epidemiological evidence that support the causal relationship between MAP and CD (Uzoigwe *et al.* 2007).

The most recent meta-analysis studies for investigating the relationship between MAP and CD indicated that there is an association between MAP and CD. The role of MAP in the aetiology of CD is not clear but should not be ignored and recommended that the potential routes of human exposure to MAP should be investigated (Feller *et al.* 2007; Abubakar *et al.* 2008; Waddell *et al.* 2008).

Many studies have investigated different aspects of the disease in farm and wild animals, however, there are comparatively few studies concerned with the contamination of food products with MAP and the effect of food processing on viability of MAP in food products of animal origin.

A systematic review, in contrast to a narrative review, is a structured process for gathering, appraising and synthesizing scientific evidence from primary studies, with minimum bias and random error (Cook *et al.* 1997). It is widely used in biomedical research, but its use in agri-food public health research is more recent with only a few examples published so far (Adkin *et al.* 2006). Systematic reviews have large potential in this field as structured concise processes for providing policy-makers with knowledge about the effectiveness of interventions, and data gaps along the food production chain from farm to fork for preventing potential food-borne pathogens (Sargeant *et al.* 2006). With this overarching aim, the specific objective of this review is to systematically collect, appraise and summarize scientific studies concerning the likelihood of contamination of dairy and meat products with MAP, and the potential changes in the quantity of MAP in dairy and meat products along their production chain, from farm to retail sale.

Materials and methods

Search strategy

The search strategy followed the general guidelines for conducting a systematic review published by the International Cochrane Collaboration (<http://www.cochrane.org/index.htm>), Centre for Reviews and Dissemination (CRD) (2001) and Sargeant *et al.* (2005, 2006). Contrary to most systematic reviews of intervention, this systematic review did not address one single specific question due to its wide scope, but several interrelated questions as listed in Table 1.

The following databases were searched by August 2007 and updated by October 2008: Medline through PubMed, CAB Direct and Science Direct. For the initial identification of primary studies the following search terms combined with 'Mycobacterium avium paratuberculosis' were used; 'dairy cattle', 'calves', 'beef cattle', 'sheep', 'goat', 'milk', 'faecal contamination', 'cheese', 'meat', 'environ-

Table 1 Questions addressed by the systematic review on the presence of MAP in food products

Number	Review question
1	What is the likelihood of infection of farm animals (cattle, sheep and goats) with MAP?
2	What is the likelihood of contamination of raw food products with MAP?
3	What is the likelihood of contamination of food products with MAP during processing?
4	What is the effect of different processing steps on MAP viability in food products?
5	What is the likelihood of post processing contamination of food products with MAP?
6	What is the likelihood of detection of viable MAP in processed food products stored on retail sale?

ment', 'cleaning', 'lairage', 'skinning', 'evisceration', 'beef', 'lamb', 'pasteurization', 'post-processing' and 'contamination and milk'.

Primary identification of relevant studies

The following criteria were used to enable primary identification of the relevant papers: (i) published in a peer-reviewed scientific journal, (ii) in English language and (iii) address at least one of the research questions (Table 1) to deem the papers relevant or irrelevant. The assessment was carried out by two independent reviewers. For the purpose of external quality assurance, a random sample of papers from both groups of studies (25 classified as relevant and 25 as irrelevant) was selected, and reviewed independently by a third reviewer.

Quality appraising

This review addresses multiple questions; therefore the papers identified as relevant used a range of study designs. In order to assess the quality of the papers we requested examples of quality appraisal checklists from members of the editorial boards of 21 scientific journals and corresponding authors of published systematic reviews in the agri-food field. However, we were unable to find a quality checklist suitable for appraising the wide range of study designs encountered in this systematic review. Therefore, in order to ensure that our quality appraisal was as consistent and unbiased as possible we developed our own minimum checklist applicable to studies with different designs, as described in Table 2. The full text of the primary relevant studies was obtained and the quality appraisal was carried out by two independent reviewers. The outcome of the appraisal was whether or not the paper suffered from methodological issues that could have affected the validity of its results according to

Table 2 Criteria for quality appraising of primary relevant studies concerning the presence of MAP in food products

Quality item	Description
The aim of the study	Study question is clearly stated, focused and appropriate
Study population	Clear and represents a part of agricultural food sector (from farm to retail)
Methodology and study design	Clear, precise and suitable for the aim of the study
Sampling technique	Mentioned and appropriate
Study environment	The study was conducted under field conditions or nearly similar with the same managerial practices in the animal farm. Experiments for isolation of MAP from food products were conducted under conditions similar to commercial production
Control groups	Animal or food product according to the study design and population
Analysis of data	Appropriate statistical analysis was done; analytical techniques are properly described and referenced.
Results	Clear with well interpretation
Discussion	Clear explanation of results and logical scientific explanation of any conflict or disagreement between results and literature review
Conclusion	Clear and supported by the results

the criteria specified in the checklist. Disagreements between the two independent reviewers were resolved by a third reviewer.

Data extraction and synthesis

Data from the primary relevant studies were extracted, summarized and organized in a qualitative manner according to the research question/s they addressed.

Results

The initial search revealed 3320 papers. After exclusion of duplications, review papers and applying the inclusion criteria, 107 papers were deemed relevant; of them, 65 papers were found to be of sufficient quality for inclusion in this review.

Likelihood of infection of farm animals with MAP

Prevalence of paratuberculosis has been investigated in different countries, mainly at sub-national level. Our systematic review revealed 18 studies, concerned with the prevalence of JD in cattle and these are summarized in Table 3. Herd and individual prevalence differed considerably between studies conducted in different regions and cattle populations. In beef cattle, the individual prevalence estimates reported ranged from 0.4% to 19% and the herd prevalence between 1.47% and 53.5%. In dairy cattle, individual prevalence ranged between 0.87% and 17.5% and herd prevalence between 2.6% and 70.2%. This review did not reveal any primary studies aimed at investigating the prevalence of paratuberculosis in sheep or goats. Two studies detected MAP in milk from sheep

and goats but the objective of these studies was not to investigate the prevalence of paratuberculosis (Grant *et al.* 2001; Muehlherr *et al.* 2003).

Likelihood of contamination of raw food products with MAP

Raw meat products

Meat may be contaminated with MAP by dissemination of the pathogen in the tissues of infected animals or by faecal contamination of the carcass with contaminated faeces. Our review revealed the following three studies that dealt with the assessment of dissemination of MAP from the gastrointestinal tract to other organs in JD infected cattle. Ayele *et al.* (2004) isolated MAP from intestinal mucosa, mesenteric, head and mediastinal lymph nodes, liver and spleen from naturally infected animals. Also MAP was isolated from organs other than gastrointestinal tract from culled dairy cows, 57% of them were without clinical symptoms of JD (Antognoli *et al.* 2008). For investigating the relationship between the clinical signs of JD and the tissue distribution of MAP, Brady *et al.* (2008) examined 21 cows from eight JD infected dairy herds and found that MAP was widely distributed in the tissues of apparently healthy animals. These studies indicate that beef from culled dairy cattle even without clinical symptoms of JD can be contaminated with MAP via dissemination of the pathogenic agent in the tissues of infected animal.

For investigating the extent of contamination of beef carcasses with MAP, swab samples were collected from the surface of carcasses from fed beef cattle aged less than 18 months and from culled cattle. MAP DNA was detected from the surface of skinned undressed carcasses

Author	Type of cattle	Country	Prevalence	
			Individual	Herd
Thorne and Hardin 1997	Beef	USA	5 ± 2%	40%
Dargatz <i>et al.</i> 2001	Beef	USA	0.4%	7.9%
Hill <i>et al.</i> 2003	Beef	USA	8.75 ± 1.5%	53.5%
Roussel <i>et al.</i> 2005	Beef	USA	3.0%	43.3%
Dreier <i>et al.</i> 2006	Abattoir	Austria	19%	N/A
Scott <i>et al.</i> 2007	Beef	Canada	1.5%	7.9%
Dieguez <i>et al.</i> 2007	Beef	Spain	1.03%	1.47%
Thorne and Hardin 1997	Dairy	USA	8 ± 3%	74%
Obasanjo <i>et al.</i> 1997	Dairy	USA	N/A	5.2%
Cetinkaya <i>et al.</i> 1998	Dairy	UK	N/A	17.4%
Boelaert <i>et al.</i> 2000	Dairy	Belgium	0.87%	18%
Muskens <i>et al.</i> 2000	Dairy	Netherlands	2.7–6.9%	31–71%
Wells and Wagner 2000	Dairy	USA	3.4%	21.6%
Corti and Stephan 2002	Dairy (milk samples)	Switzerland	N/A	19.7%
Nielsen <i>et al.</i> 2002	Dairy	Denmark	N/A	70%
Van Leeuwen <i>et al.</i> 2001	Dairy	Canada	2.6%	30 ± 10%
Hirst <i>et al.</i> 2004	Dairy	USA	N/A	2.6 ± 1.94%
Hendrick <i>et al.</i> 2005	Dairy (milk samples)	Canada	1.7%	18%
Hendrick <i>et al.</i> 2005	Dairy (serum samples)	Canada	2.6%	30%
Scott <i>et al.</i> 2006	Dairy	Canada	17.5%	70.2%
Dieguez <i>et al.</i> 2007	Dairy	Spain	3.02%	14.75%

Table 3 Studies investigating the prevalence of Johne's disease in cattle included in the systematic review

(Meadus *et al.* 2008). A relevant study was identified that was concerned with the potential microbiological contamination of the carcasses with pathogens other than MAP. This study is relevant to our research questions as an indicator for microbiological and faecal contamination of the carcasses in relation to the pre-slaughter conditions. Biss and Hathaway (1995) conducted a study in New Zealand which investigated the relationship between the preslaughter conditions of lambs and the bacterial count of the carcass. They found that in the traditional dressing system, the mean level of microbial contamination in carcasses derived from dirty, woolly, and washed lambs was higher than that of clean shorn unwashed lambs. The study shows that long wool and preslaughter washing significantly increase carcass contamination; the overall prevalence of faecal contamination was higher on the hindquarters than on the forequarters. The authors estimated that microbial contamination of carcasses derived from shorn, clean, unwashed lambs was five times lower than that from woolly, dirty and washed lambs.

Raw cows' milk

At the farm level, the sources of contamination of raw milk with MAP include direct shedding of the pathogen from clinically or subclinically infected cows, faecal contamination and mixing with contaminated milk in bulk tanks. Our review identified five studies concerned with the likelihood of contamination of raw milk with MAP.

Nauta and Van der Giessen (1998) concluded that clinically infected animals with paratuberculosis are the main sources of contamination of milk with MAP. About 244 bulk raw milk samples from approved dairy processing plants in the UK were investigated by PCR and culture for the presence of MAP, 7.8% and 1.6% of samples were found to be PCR and culture positive, respectively (Grant *et al.* 2002). A similar survey was conducted by the Food Safety Authority of Ireland in which 389 bulk raw milk samples were tested for the presence of MAP. The result of this survey revealed that 12.9% and 0.3% were positive for IMS-PCR and culture respectively (O'Reilly *et al.* 2004). In a study conducted by Taylor *et al.* (1981) in which 26 milk samples from clinically infected cows with paratuberculosis were examined by culture for the presence of MAP, nine samples were positive. In the same study, MAP was isolated from faeces, supra-mammary lymphnode, and deep udder tissue (Taylor *et al.* 1981). Ayele *et al.* (2005) tested raw milk samples, from herds with MAP positive faecal cultures and concluded that raw milk from subclinically infected animals could be contaminated with MAP. Corti and Stephan (2002) investigated the presence of MAP specific IS900 insertion sequence by PCR in bulk-tank milk samples from Swiss dairy farms and found that, out of 1384 bulk-milk samples, 19.7% were positive. In this study, the prevalence of MAP specific IS900 insertion sequence in bulk-tank milk samples in different regions of Switzerland ranged from 1.7% to 49.2%.

Raw milk of sheep and goat

Grant *et al.* (2001) investigated the presence of MAP in 104 sheep and goat raw milk samples from bulk tanks on farms (90 goat and 14 sheep) from England, Wales and Northern Ireland using culture and PCR. They found one positive sample by PCR (<1%) and no viable MAP was detected. In Norway, 340 raw milk samples from 34 dairy goat herds were examined by culture and IMS-PCR; although no viable MAP was detected by culture, 7.1% of samples were PCR positive and the authors concluded that milk may be contaminated via direct shedding or by faecal contamination and that there is a seasonal variation in faecal shedding of MAP (Djonje *et al.* 2003). Muehlherr *et al.* (2003) examined 344 goats and 63 sheep raw milk samples from bulk-tank milk in Switzerland by PCR and found that 23% of sheep samples and 23.8% of goat samples were MAP positive. In India MAP has been isolated by culture from raw milk and faeces from goats with clinical signs of JD (Singh and Vihan 2004).

Likelihood of contamination of raw food products during transportation from farm to food processing plants

Transportation of raw milk from the farm to the dairy processing plant and meat from the abattoir to the meat processing plant may result in contamination of the raw product from contaminated vehicles or mixing with contaminated products. Our review has not found primary studies that were carried out with the aim of investigating the likelihood of contamination of food products with MAP during transportation.

Likelihood of contamination of food products with MAP during processing

Meat products

Studies included in this section are concerned with the investigation of potential routes of carcass contamination during different processing steps in the abattoir and meat processing plant. It has been identified that pathogens present in a contaminated lairage can be transmitted from one batch of animals to the next and from one day to another (Small *et al.* 2003). Fleece condition is an important determinant of microbial quality of the carcass and meat products (Hadley *et al.* 1997). In sheep, it has been shown that the level of wool contamination significantly affects the level of carcass contamination irrespective of the dressing system used and that carcasses derived from shorn lambs are less contaminated than others (Biss and Hathaway 1996).

The major sources of microbial contamination in slaughterlines are: fleece, workers' hands, faecal pellets and knife blades (Bell and Hathaway 1996). It has been

concluded that carcasses produced by inverted dressing systems are less likely to become contaminated than those produced by conventional systems and that in both systems contamination increases after skin removal. In inverted dressing systems the areas of highest contamination are forequarters compared with hindquarters in conventional systems, which may be due to direct contact with fleece during rollback (Bell and Hathaway 1996).

Biss and Hathaway (1998) quantified the microbiological and visible contamination along the processing chain of lamb carcasses in two slaughterhouses using two different systems: inverted dressing system (clean, shorn unwashed lambs) and traditional dressing system (dirty, woolly washed lambs). In their study, surface swab samples from the leg and loin were taken from 25 carcasses after four different processing steps: (i) skinning, (ii) dressing, (iii) overnight chilling and (iv) boning and packaging. In the inverted dressing system, the mean aerobic plate count (APC) and *Escherichia coli* count (ECC) were low after skin removal but there was a significant increase towards packaging. In the same study, visible contamination on the surfaces of 300 carcasses after skinning and after overnight chilling was assessed. The conclusion from this study was that critical points for carcass contamination are: animal cleanliness prior to slaughter, dressing practices, staff practices and handling during chilling.

Skin removal is a critical point in carcass contamination. It has been found that sites associated with opening cuts and those exposed to direct contact with the skin during skin removal can be highly contaminated (Bell 1997). Gill *et al.* (1996) used ECC as an indicator to evaluate the hygiene and faecal contamination of beef carcasses during processing. In this study, samples were taken from the neck, brisket and rump and it was found that contamination decreased towards the end of processing. Contamination with aerobic flora as a result of skinning was similar for all sites but faecal contamination was heavier on the rump than the other sites. It was also found that trimming and washing do not completely decontaminate the carcass, but trimming significantly decontaminates the rump site. The only revealed study that specifically concerned with carcass contamination with MAP was by Meadus *et al.* (2008), in which MAP DNA was isolated from the surface of dressed carcasses which indicate that MAP like any other faecal borne pathogens can be removed or redistributed on the carcass surface by washing.

Dairy products

There are many potential sources of microbiological contamination of dairy products during processing such as mixing of pasteurized and raw milk in the processing line,

the addition of contaminated ingredients, or cross-contamination along the processing chain (Pearce *et al.* 2001). We have not identified primary studies specifically concerned with the contamination of dairy products with MAP during different processing steps.

Effect of food processing steps on MAP viability

Meat products

Our systematic review did not reveal any primary studies that were concerned with investigating the effects of different processing steps of meat products on viability and concentration of MAP. However, eight studies were identified that address the effect of some processing steps during the production of meat products on removal or decrease of the microbiological contamination of the carcass. Investigations on the effect of washing on visible and microbial contamination of ovine carcasses have shown the influence of the temperature and pressure of washing water, and that although the pre-evisceration wash may remove most of the wool contamination it has little effect on visible faecal contamination. The most effective water temperature and pressure were found to be 74°C and 13.79–27.58 bar (Biss and Hathaway 1995; Kochevar *et al.* 1997). Combinations of interventions such as hot water wash followed by lactic acid sanitizer were more significant in reducing the contamination of carcasses. The use of 2% acetic acid has been found to effectively reduce carcass contamination (Kochevar *et al.* 1997; Castillo *et al.* 1998). Bell (1997) found that the final carcass wash using cold water does not significantly reduce microbial contamination but may redistribute contamination from posterior to anterior. The same study also found that spray washing could effectively reduce the amount of faecal and microbial contamination of lamb adipose tissue without spreading contamination to the surrounding tissue. Pre-evisceration wash of ovine carcasses has little effect on uncontaminated areas of the carcass but reduces the mean APC and ECC at the site of visible contamination and may lead to redistribution of contamination to the adjacent areas (Biss and Hathaway 1996). Gorman *et al.* (1995) investigated the effect of trimming and spray washing on the removal of faecal material from artificially-contaminated beef carcasses, and found the pressure of the spray to be important in the removal of bacterial and faecal contamination; pressures above 13.79 bar significantly increased effectiveness. Spray washing may reduce 1 to 2 log CFU cm⁻² and may have an effect similar to that of hand trimming. Spray washing with a maximum pressure of 20.70 bar is recommended for removing faecal contamination of beef carcasses (Gorman *et al.* 1995). Pre-evisceration washing of beef carcasses may reduce the existing contamination and the

susceptibility of carcasses to physical and bacterial contamination as it reduces the ability of contaminants to adhere to the surfaces of the carcasses (James 1995). Sources and level of microbial contamination of beef carcasses in USA abattoirs have been investigated; samples from carcasses' surfaces (brisket, flank and rump) were taken after removal of the hide, pre-evisceration, final washing of the carcass and 24 h chilling. APC, ECC, total coliform count (TCC) and the presence of *Salmonella* spp. were examined for each sample and it was concluded that the level of carcass contamination may be influenced by season, abattoir, location within the abattoir and site of sampling and that final wash of the carcass before chilling may reduce contamination (Sofos *et al.* 1999).

In summary, the pre-slaughter condition of the animal is a significant factor affecting the microbiological quality of the final products. Faecal contamination of the carcass in the abattoir is unavoidable and different processing steps within the abattoir do not completely remove contamination.

Dairy products

Preheat treatment

The preheat treatment of raw milk includes clarification, centrifugation, separation of fat, standardization and homogenization. All of these processes may increase or decrease the concentration of MAP in contaminated raw milk or even result in its inactivation. Our review identified four studies addressing these issues. Grant *et al.* (2005a) investigated the effect of centrifugation and microfiltration of raw milk contaminated with MAP and found that from 95% to 99.9% of MAP can be removed.

A combination of homogenization and pasteurization was found to be more effective on MAP inactivation than pasteurization alone (Grant *et al.* 2005b). Similar results were obtained by McDonald *et al.* (2005) who investigated the effect of heat inactivation of MAP and noticed that the concentration of MAP in milk samples was higher post-homogenization than pre-homogenization. The authors hypothesize that this may be due to the mechanical effect of homogenization, which leads to the dispersal of MAP clumps. In a more recent study however, Rademaker *et al.* (2007) concluded that, homogenization has no effect on MAP inactivation. This finding contradicts the results of McDonald *et al.* (2005), and it is suggested that this may be due the differences in strains of MAP, protocols used or the presence of bacterial clumps (Rademaker *et al.* 2007).

Pasteurization

Our review identified seven studies concerned with the effect of milk pasteurization on MAP viability. On farm

batch pasteurization of milk at 65.5°C for 30 min has been investigated by Stabel (2001) who was unable to recover viable MAP after 28 weeks of incubation. Different studies have been applied to investigate the effect of different time temperature combinations on MAP inactivation. It has been estimated that MAP inactivation by high temperature short time pasteurization (HTST) at 72°C for 15 s ranged from 4 log₁₀ to 7 log₁₀. The rate of inactivation may depend on the primary concentration of MAP in raw milk. Subpasteurization temperature of milk for cheese production may not be sufficient for complete inactivation of MAP (Pearce *et al.* 2001; Gao *et al.* 2002; Stabel and Lambertz 2004; McDonald *et al.* 2005; Rademaker *et al.* 2007). Donaghy *et al.* (2007) showed that MAP is not completely destroyed in milk artificially contaminated with a high inoculum even after a combination of high pressure (600 MPa) and pasteurization.

Processing of dairy products

Only three relevant studies were concerned with investigating the effect of processing steps on MAP viability in cheese. Sung and Collins (2000) investigated the effects of the addition of sodium chloride and low pH on MAP viability during cheese processing. They found that sodium chloride has little or no effect on the rate of MAP inactivation while low pH significantly contributes to MAP inactivation. This effect was higher on heat treated MAP and consequently the authors suggest that heat treatment in combination with 60 days of ripening may significantly reduce MAP contamination in cheese. Spahr and Schafroth (2001) investigated the presence of MAP in hard and semihard cheese made from raw milk artificially contaminated with 10⁴ to 10⁵ CFU ml⁻¹ of deplumped MAP cells, and concluded that MAP may not be able to multiply in cheese due to its fastidious growth. MAP concentration decreased slowly during the ripening period and viable MAP was qualitatively detected in 120-day

cheese. The same study also concluded that temperature and low pH are the most important factors in MAP inactivation and that a ripening period (at least 90–120 days) of raw milk cheese may inactivate 10³ to 10⁴ cells of MAP per gram. Donaghy *et al.* (2004) investigated the persistence of MAP during the manufacture and ripening of Cheddar cheese and found a very low inactivation rate of MAP and to reduce a 1 log₁₀ concentration of MAP requires at least three months ripening period under low temperature.

Likelihood of post-processing contamination of food products with MAP

There are many potential sources of post-processing contamination. Pasteurized milk for example may be contaminated from filling machines, or may be mixed with raw milk as a result of leakage in the processing line (Pearce *et al.* 2001). There were no available data concerning post-processing contamination of food products with the exception of one study that focused on the development of bacterial biofilms in dairy processing lines and found that they may act as a source of post-pasteurization contamination (Austin and Bergeron 1995).

Likelihood of presence of MAP in food products on retail sale

There is one primary study revealed by this systematic review concerned with the detection of MAP from meat products on retail sale, a survey carried out by Jaravata *et al.* (2007) in which 200 ground beef samples were examined by PCR for the presence of MAP and were all found to be negative. Many studies have attempted the detection of MAP in milk and dairy products on retail sale. Table 4 gives a summary of the results of relevant studies identified.

Table 4 Studies concerned with the detection of MAP from dairy products on retail sale included in the systematic review

Authors	Country	Samples	Results (%+ve)	
			PCR	Culture
Gao <i>et al.</i> 2002	Canada	710 retail pasteurized milk samples	15%	0%
Grant <i>et al.</i> 2002	UK	567 commercially pasteurized milk samples	11.8%	1.8%
O'Reilly <i>et al.</i> 2004	Ireland	357 pasteurized milk samples	9.8%	0%
Aylee <i>et al.</i> 2005	Czech Republic	244 commercially pasteurized milk samples	N/A	1.6%
		100 locally pasteurized milk samples derived from infected herds	N/A	2.0%
Ellingson <i>et al.</i> 2005	USA	702 retail pasteurized whole milk samples	N/A	2.8%
Ikonomopoulos <i>et al.</i> 2005	Greece and Czech Republic	Retail cheeses (feta, soft, hard and semi hard cheese)	31.7%	3.6%
Clark <i>et al.</i> 2006	USA	98 samples of retail cheese curds	5%	0%
Stephan <i>et al.</i> 2007	Switzerland	143 raw milk cheese samples (soft, semihard and hard)	4.2%	0%

Conclusions

Although a systematic review is a time consuming process, it has the advantage of being a structured, transparent and repeatable method for identifying, appraising, summarising and synthesizing scientific evidence from primary studies of a good quality. The scope of this systematic review was very broad since we targeted all scientific evidence relating to the presence of MAP along the different production pathways, from farm to retail sale, for both meat and dairy products. As we have limited this review to papers published in peer-reviewed journals, material published in non-peer reviewed journals or reports has not been considered.

Accurate and unbiased estimates of the prevalence of JD at herd and individual animal level for non dairy cattle, sheep and goats are scarce especially in Europe. This finding is in agreement with that of (Nielsen and Toft 2009). The results of prevalence studies that we identified suggest that the likelihood of contamination of raw milk with MAP in most studied regions is significant. Pasteurized milk is the only product which has been repeatedly investigated for the presence of MAP and the results of most of these studies indicate that pasteurized milk is not always MAP free. Furthermore, these studies suggest that the effectiveness of pasteurization in inactivating MAP is affected by the initial concentration of the agent in raw milk. Some types of cheeses have been investigated and the conclusion is that they are not always completely free of MAP. There are no primary studies that investigated the presence of MAP in other dairy products or the effect of different processing steps, other than pasteurization, on MAP inactivation.

The potential contamination of meat and meat products with MAP cannot be ruled out. However, prevalence data are particularly lacking for non-dairy herds and almost no data are available on the effects of meat processing on MAP viability and contamination.

Given the current knowledge, it is reasonable to assume that the risk of contamination of dairy and meat products with MAP is directly related to the extent of dissemination of MAP in the tissues of infected animals and the amount of faecal contamination which is likely to differ according to animal species and production system. The farm and abattoir are therefore critical points in reducing the risk of contamination with MAP. Along the food production chain certain processing steps are likely to influence the level of MAP contamination in the final product.

To reduce human exposure to MAP via consumption of dairy and meat products quantitative studies are needed for estimating the amount of MAP shedding in milk and faeces, the extent of dissemination of MAP in

tissues of infected animals, the amount of faecal contamination of milk and carcasses and the effect of different processing steps of different dairy and meat products on MAP inactivation. New techniques are required for early detection of infected animals in order to decrease the environmental contamination with MAP and consequently decrease disease spread and contamination of food products. Processing of milk and meat products from JD infected farms should have special attention.

Although at the current stage the relationship between JD and CD is not fully understood, in the light of current available data, the likelihood of dairy and meat products being contaminated with MAP on retail sale shouldn't be ignored.

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