ORIGINAL ARTICLE

Infectious disease risks associated with occupational exposure: a systematic review of the literature

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ABSTRACT

Employees in different types of work may be intentionally or accidentally exposed to biological agents. Improved risk assessment is needed to identify opportunities to prevent work-related infectious disease. The objective of the current study was to perform a systematic literature review of work-related infectious disease to assist in the identification of occupational infectious disease risks. A literature search of papers on work-related infectious disease published between 1999 and 2008 yielded 1239 papers of which 242 met the selection criteria and were included in the review. The results of the systematic literature review were arranged in a matrix of occupational groups and exposure pathways. Increased risk from infectious diseases appeared to be concentrated in specific professions. Healthcare workers, workers in contact with animals, laboratory workers and refuse workers seem to have the highest risk of infection by a variety of pathogens. However, pathogens reported to be associated with closely related professions were different, indicating qualitative under-reporting. Arranging the results of this systematic review on work-related infectious diseases in a matrix of occupational groups and exposure pathways allowed the reliable identification of exposure hazards for specific occupational groups beyond currently reported diseases.

What this paper adds

- Employees in different types of work may be intentionally or accidentally exposed to biological agents.
- Improved risk assessment is needed to identify opportunities to prevent work-related infectious disease.
- Few occupational groups have evidence of exposure to infectious pathogens.
- A matrix of occupational groups and exposure pathways allowed identification of exposure hazards for specific occupational groups beyond those currently reported.
- The exposure matrix may facilitate company medical officers to identify links between pathogens, disease and certain job titles.

INTRODUCTION

Biological agents encompass an enormous variety of micro-organisms, toxins and allergens that may harm human health, including those that cause infectious disease. Employees in many lines of work may be exposed to infectious agents, putting them at risk of disease. This exposure can occur in different ways, either through intentional use of specific microorganisms (laboratories, biotechnological industries), as more or less accidental co-exposures resulting from processes which involve many different microorganisms (composting, recycling, waste water recycling), through animal contact (agriculture, food processing) or through contact with humans (healthcare, education). Thus, some work related infectious diseases occur relatively exclusively in certain occupations, while others are less connected to the work environment.

Worldwide, an estimated 320 000 employees die annually from work-related infectious disease, 5000 of whom are in the EU.[1–4] Morbidity from work-related infectious disease is expected to be even higher, although the true extent of incident cases is difficult to establish. In the Netherlands, 553 cases were reported in the period 2001–2006, of which two were fatal.[5] The legally compulsory registration covering 35 different infectious diseases reported by primary care physicians to municipal health services yields five times more occupational cases than the number of cases reported by occupational physicians. The overlap between the two case series is limited, indicating inadequate compliance with legal requirements and, in particular, poor recognition of occupational infectious diseases.[5] The lack of distinctive characteristics of work-related infectious disease obscures the link between work and disease, and hence incident cases of work-related infectious disease are under-reported in designated surveillance systems.[6] Moreover, there are multiple reasons why failure to detect infectious diseases and association with workplace exposures could occur: occupational disease monitoring programs may not cover the entire workforce, or may be restricted to certain diseases with mandatory reporting, workers may not always have access to occupational healthcare, physicians may not have access to the proper diagnostic tools, etc.

Undisputedly, however, work-related infectious disease may result in harm to the health of an individual and may impose a potentially high disease burden on a population.

Objective of this study

The objective of the current study was to perform a systematic literature review of work-related infectious disease to assist in the identification of occupational infectious disease risk. The results of the systematic literature review were arranged in

a matrix of occupational groups and exposure pathways so that a more comprehensive list of hazards could be identified from the reported associations.

METHODS

Definitions

Occupational exposure is defined as exposure to potentially harmful chemical, physical or biological agents that occurs as a result of occupational factors. This study focuses on biological agents, and is limited to work-related infectious disease, that is, infectious disease that is caused through work-related exposure or exacerbated by work-related factors.[7] Biological agents that are non-infectious are excluded, such as mould allergens that can trigger allergies, and mite infestation. The study focused on workers in industrialised countries, but includes excess risks for developing infectious disease through work-related travel, for instance by army forces posted overseas or airline personnel. Surveillance data have shown that the majority of reported work-related infectious diseases in the Netherlands were contracted abroad.[5] This means that this research was not restricted to infectious pathogens in Western Europe, but concerned all pathogens found in the literature which are a hazard for workers in industrialised countries.

The literature review was conducted taking into account the methodological recommendations by Waddell *et al*.[8]

Literature search

Articles published in 1999 through 2008 were searched in Medline. English, Dutch, German, French, Italian and Spanish articles were included. An extensive electronic search strategy was developed in collaboration with a librarian who had broad experience with systematic reviews. Search terms used were: work, workplace, workers, laborers, employees, occupational, communicable diseases, zoonoses, environmental microbiology, virus-diseases, bacterial infections, parasitic disease, mycosis, viruses, bacteria, parasites, helminthes, fungi, infection, infectious, microorgan*, micro-organis*, pathogens, pathogenic, virus, viral, bacteria*, fungi, fungal, fungus, mould*, mycoses, parasit*, helminth*, zoonot*, zoonos*, bioaerosol*, air microbiology, occupational-diseases, occupational exposure, occupational health, incidence, prevalence, epidem*, seroepidem*, occurrence, seroprevalence, exposure, exposed, etiology, burden or risk*, emerging, risk-factors, risk-assessment. The search profile is shown in the online supplementary appendix.

Publications included in the review had to meet the following inclusion criteria:

- The study (or at least an abstract) was published in English, Dutch, German, French, Italian or Spanish in the period 1999–2008.
- The study concerned disease due to exposure to infectious pathogens among employees.
- The study concerned employees of a specific occupational group.
- The study concerned specified pathogen(s).
- The study reported symptomatic disease and/or seroconversion, not merely exposure.
- Symptomatic disease was causally linked to work-related factors and/or seroconversion was higher compared to an appropriate reference group.

Relevant papers were selected by screening the titles (first step), abstracts (second step) and entire articles (third step) retrieved through the database searches. The screening of titles and abstracts was conducted independently by two researchers (JH and LT). Differences were resolved by discussion.

Results from the literature review were first arranged in tabular form, listing all reported associations between pathogens and job titles or broader occupational groups. The International Standard Classification of Occupation (ISCO) of the International Labour Organization (ILO), version 08 was used to classify job titles. ISCO classifies job titles in four levels of aggregation. We used ISCO-08 level 3, which distinguishes 150 job titles or broader occupational groups. For some broad groups, or where very specific associations were reported, level 4 subclassifications were considered. Subsequently, all pathogens were classified according to their proximate sources of exposure and site of entry into the body. Job titles or broader occupational groups were then cross-tabulated with pathogen groups to generalise from the reported associations to broader categories of pathogens with similar transmission characteristics.

RESULTS

We identified 1239 articles that met our search terms. In the first round (scanning the titles), 459 articles were retained. Based on evaluation of the abstracts, 217 articles were excluded because they did not meet our inclusion criteria. The remaining 242 articles were systematically reviewed on job title or occupational group involved and associated pathogen. Figure 1 shows a flow chart of the literature screening process.

Job titles or occupational groups, ISCO-08 codes and associated pathogens are shown in table 1. The literature review identified 31 occupational groups (at ISCO-08 level 3) that were at risk of infectious disease. For some job titles a single pathogen was reported, for instance fishermen and *Anasakis simplex*. Other job titles or broader occupational groups were associated with a variety of infectious pathogens, for example, healthcare workers, laboratory workers and those working with animals. The online supplementary appendix includes a list of all reported associations between pathogens and job titles separately for each article included in the review.

All pathogens identified in the literature search were classified in a matrix according to site of entry into the human body (skin, uro-genital tract, respiratory tract and gastro-intestinal tract[9]) and source of exposure (human-to-human, animal-to-human and environment-to-human) (table 2). Where necessary,

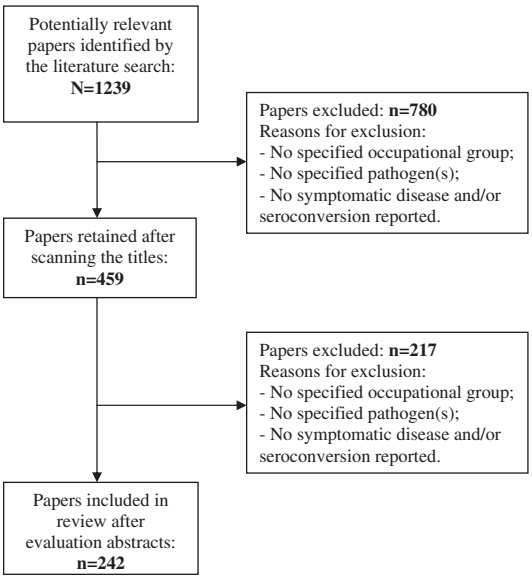

Figure 1 Flow chart of literature screening process.

Table 1 Work-related pathogens by specific job title or broader occupational groups

Occupation	ISCO code	Pathogen
Abattoir workers	751	(Methicillin resistant) *Staphylococcus aureus*, (swine) influenza virus, *Brucella* spp., *Campylobacter* spp., *Coxiella burnettii*, *Escherichia coli*, hepatitis B virus, hepatitis E virus, *Leptospira hardjo*, *Leptospira pomona*, *Streptococcus pyogenes*, *Toxocara canis*
Airline personnel	511	Hepatitis E virus
Animal carers	516	*Bartonella hensalae*, *Borrelia burgdorferi*, *Capillaria hepatica*, *Chlamydophila psittaci*, hantavirus, influenza virus, *Leptospira* spp., simian foamy virus, simian parvovirus, simian type D retrovirus, *Toxocara canis*, *Toxoplasma gondii*
Archaeologists	211	*Coccidioides immites*
Armed forces	01	*Leishmania* spp.
Childcare providers	531	*Cryptosporidium parvum*, Cytomegalovirus, *Giardia lamblia*, hepatitis A virus, parvovirus, varicella zoster virus
Cleaners	515	Hepatitis A virus, hepatitis B virus, *Mycobacterium tuberculosis*
Dental care workers (dentist 266, dentist assistant 325)	226, 325	Hepatitis B virus, hepatitis C virus, HIV, etc
Divers	754	*Campylobacter jejuni*, enteroviruses, *Pseudomonas aeruginosa*
Farm labourers (animal handlers)	921	(Methicillin resistant) *Staphylococcus aureus*, (swine and avian) influenza virus, *Borrelia burgdorferi*, *Brucella* spp., *Campylobacter* spp., *Chlamydophilia psittaci*, *Clostridium tetani*, *Coxiella burnettii*, *Escherichia coli*, *Helicobacter pylori*, hepatitis E virus, *Leptospira icterohaemorrhagiae*, *Mycobacterium bovis*, *Strongyloides stercoralis*, *Toxocara canis*, *Toxoplasma gondii*, West Nile virus
Farm workers, animals	612	(Methicillin resistant) *Staphylococcus aureus*, (swine and avian) influenza virus, *Borrelia bergdorferi*, *Brucella* spp., *Campylobacter* spp., *Chlamydophilia psittaci*, *Clostridium tetani*, *Coxiella burnettii*, *Helicobacter pylori*, hepatitis E virus, *Leptospiro icterohaemorrhagiae*, *Mycobacterium bovis*, *Streptococcus suis*, *Strongyloides stercoralis*, *Toxocara canis*, *Toxoplasma gondii*, West Nile virus
Farm workers, crops	611	*Borrelia bergdorferi*, *Clostridium tetani*, *Coxiella burnettii*, *Escherichia coli*, *Leishmania* spp., *Strongyloides stercoralis*, *Toxocara canis*
Fishermen	622	*Anasakis simplex*
Fishmonger	751	*Anasakis simplex*
Forestry workers	621	*Anaplasma phagocytophilum*, *Borrelia burgdorferi*, *Coxiella burnetii*, hantavirus, *Rickettsia conorii*, *Ricketssia helvetica*, tick-borne encephalitis virus, *Toxoplasma gondii*
Funeral service workers	516	*Mycobacterium tuberculosis*
Gardeners	611	*Francisella tularensis*
Healthcare assistants	532	*Helicobacter pylori*
Healthcare workers (nurses and midwives 222, nurse or midwife assistant 322)	222, 322	(Methicillin resistant) *Staphylococcus aureus*, *Bordetella pertussis*, cytomegalovirus, *Helicobacter pylori*, hepatitis A virus, hepatitis B virus, hepatitis C virus, hepatitis E virus, human herpes virus, HIV, human parvovirus, influenza virus, measles virus, monkey pox virus, mumps virus, *Mycobacterium bovis*, *Mycobacterium tuberculosis*, rubella virus, *Salmonella* spp., SARS coronavirus, *Streptococcus pyogenes*, vancomycin-resistant enterococci, varicella zoster virus
Hospital dietary workers	941	*Coxiella burnettii*, hepatitis A virus
Hunter, trapper	622	*Borrelia burgdorferi*, *Brucella* spp., *Echinococcus granulosis*, *Echinococcus multilocularis*, *Ehrlichia chaffeensis*, *Francisella tularensis*, hantavirus, *Leptospira icterohaemorrhagia*, *Leptospira interrogans*, *Toxocara canis*
Laboratory workers	321	(Methicillin resistant) *Staphylococcus aureus*, *Bartonella hanselae*, *Brucella* spp., *Clostridium difficile*, *Coxiella burnettii*, *Giardia lamblia*, HIV, influenza virus, *Mycobacterium tuberculosis*, *Neisseria meningitidis*, *Pasteurella multocida*, rhinovirus, *Salmonella* spp., *Shigella* spp., simian foamy virus
Medical doctors	221	Hepatitis B virus, hepatitis C virus, HIV, *Mycobacterium tuberculosis*, SARS coronavirus
Microbiologists	213	*Neisseria meningitidis*
Plant and machine operators and assemblers	81	*Histoplasma capsulatum*, *Legionella pneumophila*, *Mycobacterium chelonae*
Prison guards	541	*Mycobacterium tuberculosis*
Sex workers (also adult movie actors)	516	*Chlamydia trachomatis*, hepatitis B virus, hepatitis C virus, herpes virus, HIV, human papilloma virus, human T-lymphotrophic virus, *Neisseria gonorrhoeae*, *Treponema pallidum*, *Trichomonas vaginalis*
Teachers, primary	234	Cytomegalovirus, *Neisseria*
Veterinarian assistants	324	(Methicillin resistant) *Staphylococcus aureus*, (swine) influenza virus, *Brucella* spp., *Bartonella hanselae*, *Campylobacter* spp., *Chlamyodphila psitacci*, *Clostridium tetani*, *Coxiella burnettii*, *Pasteurella multocida*, *Salmonella* spp., *Toxoplasma gondii*
Veterinarians	225	(Methicillin resistant) *Staphylococcus aureus*, (swine) influenza virus, *Bartonella hanselae*, *Brucella* spp., *Campylobacter* spp., *Chlamyodphila psittaci*, *Clostridium tetani*, *Coxiella burnettii*, hepatitis E virus, monkey pox virus, *Pasteurella multocida*, *Salmonella* spp., *Toxocara canis*, *Toxoplasma gondii*
Waste collectors	961	*Brucella* spp., *Helicobacter pylori*, hepatitis A virus, hepatitis B virus, hepatitis C virus, *Toxoplasma gondii*

ISCO, International Standard Classification of Occupation.

pathogen groups were further subdivided to reflect specific exposure scenarios. Thus, infections of the skin and mucous membranes due to human–human transmission were subdivided in two groups relating to needle-stick injuries or other rupture of the normal skin barrier and infections of the skin and mucous membranes. Likewise, infections of the skin

and mucous membranes due to animal–human transmission were subdivided in those resulting from bites or direct animal contact, and those from bites by vectors (mosquitoes and ticks). Environmental sources were subdivided to reflect the main reservoirs of the pathogens (human, animal or inanimate). This classification results in groups of pathogens with similar transmission pathways.

This approach is made explicit in table 3, where we cross-reference the ISCO-08 levels as described in table 1 with pathogen categories as described in table 2. Pathogens reported for one of the professions at any ISCO level may be considered a hazard to other job titles at that level. Documented risks of one or more pathogens in a specific category may be extended to other pathogens in that category to identify additional hazards

Table 2 Work-related pathogens by proximate sources of exposure and site of entry in the human body

	Proximate sources of exposure		
Site of entry	**Human***	**Animal***	**Environment†**
Skin and mucous membranes‡	Needle-stick injuries Hepatitis B virus Hepatitis C virus HIV Human herpes virus 8 Cutaneous infections (Methicillin-resistant) *Staphylococcus aureus* *Streptococcus pyogenes* *Streptococcus suis* Cytomegalovirus	Mammals (bites or direct contact) *Brucella* spp. Hantavirus Rabies virus *Leptospira hardjo* *Francisella tularensis* *Bartonella henselae* *Pasteurella multocida* (Methicillin-resistant) *Staphylococcus aureus* Simian foamy virus Simian type D retrovirus Monkey pox virus Mosquito bites *Leishmania* spp. West Nile virus Tick bites *Anaplasma phagocytophilum* *Borrelia burgdorferi* *Ehrlichia chaffeensis* Tick-borne encephalitis virus *Rickettsia* spp.	Human reservoirs *Strongyloides stercoralis* Animal reservoirs *Clostridium tetani* *Leptospira icterohaemorrhagia* Inanimate reservoirs *Pseudomonas aeruginosa*
Uro-genital tract	Human papilloma virus *Neisseria gonorrhoeae* *Chlamydia trachomatis* HIV Human T-lymphotrophic virus *Treponema pallidum* Hepatitis B virus *Trichomonas vaginalis* Herpes virus		
Respiratory tract	*Bordetella pertussis* *Streptococcus pyogenes* *Neisseria meningitides* Varicella zoster virus Influenza virus SARS coronavirus Rubella virus Mumps virus Measles virus *Mycobacterium tuberculosis* Parvovirus Rhinovirus Monkey pox virus	Avian influenza virus Simian parvovirus Influenza virus *Mycobacterium tuberculosis*	Animal reservoirs *Coxiella burnettii* *Francisella tularensis* *Histoplasma capsulatum* Hantaviruses *Chlamydophilia psittaci* Inanimate reservoirs *Coccidioides immites* *Enterobacteriaceae* (eg, *Klebsiella* spp., *Enterobacter* spp.) *Legionella pneumophila* *Mycobacterium chelonae*
Gastro-intestinal tract	*Helicobacter pylori* *Giardia lamblia* *Cryptosporidium parvum*	*Cryptosporidium* spp. *Salmonella* spp. *Campylobacter* spp. *Escherichia coli*	Human reservoirs Hepatitis A virus Hepatitis E virus *Clostridium difficile* Animal reservoirs Shiga-toxin producing *Escherichia coli* *Brucella* spp. Hepatitis E virus *Salmonella* spp. (non-typhoidal) *Campylobacter* spp. *Toxocara canis/Toxocara cati* *Shigella* spp. *Cryptosporidium parvum* *Echinococcosis multilocularis* *Echinococcus granulosis* *Anasakis simplex* *Toxoplasma gondii* *Capillaria hepatica* *Mycobacterium bovis*

*Including indoor environment.
†Food, water, soil and air.
‡Including eyes and ears.

Table 3 Infectious disease risks by ISCO-08 code and pathogen category

ISCO-08 level	Title	Pathogen category*																
		HSn	HSc	HU	HR	HG	Asd	Asm	Ast	AR	AG	ESh	ESa	ESi	EU	ERa	ERi	EGh	EGa
1	Managers																		
2	Professionals																		
211	Physical and earth science professionals																X		
213	Life science professionals				X														
221	Medical doctors	X			X														
222	Nursing and midwifery professionals	X	X		X	X												X	X
225	Veterinarians		X				X			X	X		X			X			X
226	Other health professionals (dentists)	X																	
234	Primary school and early childhood teachers		X		X														
3	Technicians and associate professionals																		
321	Medical and pharmaceutical technicians		X		X	X	X				X					X		X	X
322	Nursing and midwifery associate professionals	X	X		X	X	X											X	X
324	Veterinary technicians and assistants		X				X			X	X		X			X			X
325	Other health associate professionals (dental assistants)	X			X														
342	Sports and fitness workers											X							
4	Clerical support workers																		
5	Service and sales workers																		
511	Travel attendants, conductors and guides																		X
515	Building and housekeeping supervisors	X			X													X	
516	Other personal services workers																		
5164	Pet groomers and animal care workers				X		X		X	X	X					X			X
5169	Funeral service workers				X														
5169	Sex workers			X															
531	Childcare workers and teachers' aides		X		X	X												X	
532	Personal care workers in health services					X													
541	Protective services workers				X														
6	Skilled agricultural, forestry and fishery workers																		
611	Market gardeners and crop growers						X	X				X	X			X	X		X
612	Animal producers		X		X	X	X	X	X		X	X	X			X			X
621	Forestry and related workers						X		X							X			X
622	Fishery workers, hunters and trappers																		
6222	Inland and coastal waters fishery workers																		X
6224	Hunters and trappers						X		X				X			X			X
7	Craft and related trades workers																		
751	Food processing and related trades workers		X		X		X			X	X					X			X
754	Other craft and related workers										X			X			X		X
8	Plant and machine operators, and assemblers																		
81	Stationary plant and machine operators					X										X	X		
9	Elementary occupations																		
921	Agricultural, forestry and fishery labourers		X		X	X	X	X			X	X	X			X			X
941	Food preparation assistants															X			X
961	Refuse workers	X				X	X											X	X
0	Armed forces occupations																		
01	Commissioned armed forces officers							X											

*First letter: **H**uman; **A**nimal, **E**nvironment; second letter: **S**kin and mucous membranes, **U**ro-genital tract, **R**espiratory tract, **G**astro-intestinal tract; third letter: **n**eedle-stick, **c**utaneous, **d**irect contact, **m**osquito bites, **t**ick bites, **h**uman reservoirs, **a**nimal reservoirs, **i**nanimate reservoirs; see also table 3.
ISCO, International Standard Classification of Occupation.

for consideration in risk assessment. The extrapolation does not directly identify risks, as even within the same profession not every worker will be exposed to a certain pathogen. Furthermore, many pathogens that have animals as their primary reservoir may also be transmitted by (indirect) environmental contact.

That this approach is plausible is shown by similarities between the pathogens associated with the job titles veterinarian and veterinarian assistant (table 1). Diseases due to monkey pox virus, *Toxocara canis*, hepatitis E virus and influenza virus have only been reported among veterinarians. However, it is highly likely that veterinarian assistants, who perform similar duties and operations, are at risk for developing the same infections. The likelihood of developing disease may differ, but this aspect was not further examined since available information did not allow such quantification. The cross-tabulation in table 3 shows that both veterinarians and veterinary assistants are at risk from exposure to the same categories of pathogens. By combining tables 2 and 3 we can then extend the hazard characterisation, suggesting, for example, that both veterinary professions are also at increased risk of illness from *Francisella tularensis*, *Histoplasma capsulatum* and hantaviruses. These pathogens have not yet been reported in specific associations with these professions, but have similar transmission pathways and their potential to cause illness among workers has been associated with other, related professions.

Increased risks for the development of infectious disease are particularly associated with healthcare workers (levels 221, 222, 322, 325), professions with direct or indirect animal contact (levels 225, 324, 612, 622, 921) and to a lesser extent technicians in the life sciences (321) and refuse workers (961). For healthcare workers, in particular pathogens that spread from human-to-human contact and through the environment are important. Human-to-human spread occurs chiefly via the skin (needle-stick injuries and cutaneous infections), the respiratory system and the gastro-intestinal tract. The latter is also the exit and entry port for spread through the environment.

Livestock farmers and farm workers involved in animal handling are predominantly predisposed to zoonoses and pathogens with an animal reservoir that are spread through the environment. Zoonoses also pose a risk for veterinarians, veterinary staff and animal technicians. Laboratory animal workers are exposed to a variety of pathogens, depending on the type of laboratory work that they perform. One particular pathogen hazardous to various occupational groups is *Mycobacterium tuberculosis*, which has been associated with healthcare workers, cleaners, funeral service workers, laboratory workers, medical doctors and prison guards.

DISCUSSION

Work-related infectious diseases concern a wide variety of pathogens and occupational groups. Arranging the results of this systematic review on work-related infectious disease in a matrix of occupational groups and exposure pathways allowed the identification of exposure hazards for specific occupational groups beyond currently reported diseases.

The extrapolation of exposure hazards to other occupational groups raises the obvious question to what extent occupational groups are similar regarding their exposure hazards. We found that different associations have been reported for some professions with similar exposure patterns to putative pathogen sources. For example, gardeners are associated with disease due to *F tularensis*, whereas this pathogen was not reported in association with farm crop workers. Nevertheless, both professions are strongly exposed to soil-borne pathogens and it is likely that their risk profiles are very similar. This discrepancy for similar job titles is indicative of under-reporting of work-related disease risks in the current literature. As both job titles are assigned to the same ISCO-08 level, the hazard assessment can be generalised by assuming that all pathogens reported for one of the professions at any ISCO level can be considered a hazard for other job titles at that level. Workers from different professions in the same ISCO category perform similar tasks and actions in similar environments and thus are exposed to similar hazards. However, such similarities may not exist in residual categories of the ISCO classification, such as 226 (other health professionals) and 516 (other personal services works). Therefore, we did not extend the hazard characterisation and provided specific job descriptions. Likewise, even though childcare providers have only been documented to have been infected with six pathogens, these fall into four different categories. Our approach to generalisation suggests that these workers might also be at risk from all other pathogens in these categories, increasing the number of potential hazards to 20. Nonetheless, when interpreting the results of this study, it should be noted that even within the same profession not every worker will be exposed to a certain pathogen.

A limitation of this study is that the literature review was restricted to papers published in the period 1999–2008. Established and important occupationally-induced infections were recognised prior to 1999 and may not have been included in more recent publications and consequently in this review because they are no longer new findings. Furthermore, the search profile may not have yielded all articles on occupational exposure to infectious disease. In the light of this limitation, we recommend further exhaustive searches using the exposure matrix.

The exposure matrix that resulted from the literature review showed that relatively few occupational groups have evidence of exposure to infectious pathogens. However, healthcare workers and animal contact professions in particular are reported to be at increased risk of infection by a variety of pathogens. Healthcare workers are predominantly exposed to pathogens that are spread by human-to-human contact and enter the body via the skin. An obvious exposure route is needle-stick injuries, which expose healthcare workers as well as laboratory workers to blood-borne pathogens such as hepatitis B and C virus and HIV. There are approximately 15 000 needle-stick injuries each year in the Netherlands, 6500 of which occur in hospitals (among an exposed population of approximately 173 000 individuals).[5] Some of the high-risk needle-stick injuries also occur among healthcare workers outside the hospital setting working with individuals with a high prevalence of blood-borne infectious disease.[10] The risk of hepatitis C virus infection after a needle-stick injury is approximately 3% per year, and for HIV this risk is 0.3% per year.[11 12] Transmission via needle-stick injury may be prevented by vaccination of healthcare workers (hepatitis B virus vaccination), needle safety devices and education of healthcare workers. Cutaneous and gastro-intestinal transmission are also important exposure routes for healthcare workers and are closely linked to hand hygiene. Research showed that hand hygiene compliance is only 40%.[13 14]

Zoonoses are another notable group of work-related infectious diseases. Our review showed that farmers, abattoir workers, animal carers, veterinarians, hunters and gardeners are at increased risk of exposure. Zoonoses that are spread through close contact with mammals, such as *Brucella* spp., were of particular importance. In the Netherlands, the most frequently

reported work-related zoonotic infections are caused by *Salmonella* spp. The fact that this pathogen is well known and widely diagnosed may have led to other pathogens being under-reported. This is also suggested by the fact that blood-borne pathogens are more frequently reported compared to zoonoses. In the Netherlands, with a labour force of 7.8 million people, approximately 20 cases of work-related infectious disease due to blood-borne pathogens (hepatitis A, B and C virus, HIV) are reported annually compared to eight cases of work-related disease due to zoonoses.[5] This smaller number of registered cases may be due to a smaller risk of infection, but it seems more likely that there is not a clear link between work and zoonoses because they are believed to be less threatening to life or quality of life or because they are not adequately recognised. The link with blood-borne disease is clearer for healthcare workers, especially in the case of needle-stick injury which involves serological testing of the worker and additional psychological distress.

Evidence from the Netherlands and the UK indicates that only a small number of work-related infectious diseases are reported to the designated registration systems.[5 6] Both studies point out that an important cause of under-reporting is the difficulty of identifying a link between the disease and work related exposure. Registration may be improved by educating company medical officers to associate disease with employment. The exposure matrix may facilitate company medical officers to identify a putative link between pathogens, disease and certain job titles. This would be helpful during the hazard identification stage in a work risk assessment.[15] Better registration of work-related infectious disease is of the utmost importance, since it will help those concerned understand the size of the problem and will indicate the preventive measures that are required. Moreover, it will offer an opportunity to evaluate the preventive measures that have been undertaken. We consider this matrix approach as a promising start which can easily be expanded and updated. Due to the incomplete nature of the peer-reviewed literature, expert elicitation may be considered as an appropriate complement to this systematic review. A more comprehensive classification of occupational infectious diseases might include surveys in specific job categories at high risk of exposure, rather than symptomatic disease, to a group of related pathogens identified in table 2.

In conclusion, our review showed that farmers, abattoir workers, animal carers, veterinarians, hunters and gardeners are at increased risk of exposure to work-related infectious disease. The exposure matrix derived from this literature review showed that the number of occupational groups for which evidence is available that exposure to infectious pathogens is present is relatively small. Healthcare workers and animal contact professions in particular are reported to be at increased risk of infection by a variety of pathogens. Arranging the results of this systematic review on work-related infectious disease in a matrix of occupational groups and exposure pathways allowed reliable identification of exposure hazards for specific occupational groups beyond currently reported diseases.

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