Systematic review of the methods and frequency for undertaking workplace respiratory health surveillance

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Early identification of work-related respiratory disease (WRRD) is associated with improved health outcomes and benefits for other workers. Respiratory health surveillance (HS) is a scheme of repeated health checks used for the early identification WRRD. Health and Safety law in Great Britain requires employers to implement HS when workers remain exposed to health risks even after exposure mitigation measures have been put in place.

The evidence-base that underpins respiratory HS has not been reviewed systematically since 2012. This research was commissioned to systematically review and consider any evidence that relates to respiratory HS to ensure that HSE's guidance on HS remains relevant and appropriate.

The review found no evidence to support changes in HSE's guidance on respiratory HS, equally no evidence was found to support changes in the frequency of or tools used for respiratory HS. Evidence gaps were identified for the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness.

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Systematic review of the methods and frequency for undertaking workplace respiratory health surveillance

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Key Messages

Workplace exposures to hazardous substances can negatively impact on workers' respiratory health. Early identification of work-related respiratory disease (WRRD) can improve disease outcomes and benefit other workers. The principal aim of respiratory health surveillance (HS) is early detection of WRRD and prompt action regarding the affected individual and exposed workforce. Respiratory HS is not a replacement for good exposure control, for which the main aim is primary prevention of WRRD. WRRD have varied symptom latency, clinical presentations, diagnostic algorithms, and management. The practical and cost implications of respiratory HS influence its implementation in Great Britain.

The evidence-base for respiratory HS has not been reviewed systematically since 2012. This research was commissioned to systematically review the evidence underpinning respiratory HS in relation to five a priori defined questions related to existing HSE guidance:

1. is there any evidence that the frequency of respiratory HS should be changed (from the approach currently adopted in Great Britain)?
2. is there any evidence that the techniques (mostly using questionnaires and lung function testing) used for respiratory HS should be changed?
3. does either the frequency of, or the technique used, for respiratory HS vary depending on the disease being considered (e.g., questionnaire and/or lung function testing for occupational asthma)?
4. should the type of HS vary by the hazard e.g., flour vs isocyanates?
5. what are the knowledge gaps or conflicting evidence in relation to HS to inform the future needs of HSE's health strategy to prevent work-related lung diseases?

The review found no evidence to support changes in respiratory HS. The studies included were heterogenous in study question, design, and methodology, and reporting, and there was a lack of standardisation between studies.

Most studies included focussed on early detection or diagnosis of asthma, obstructive airways disease, or pneumoconiosis. The majority were cross-sectional in design and no randomised studies were identified. Most studies looked at the contribution of HS to earlier diagnosis. Secondary health effects, effects on other exposed workers, barriers to implementation, and costs were not commonly explored.

There was no evidence to support changes in the frequency of or tools used for respiratory HS. Further research is needed to evaluate the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness.

Future research programmes should also continue to raise awareness of the risks of WRRD among employers, employees, healthcare professionals, and the general public.

Executive Summary

Background

Work and workplace exposures can negatively impact on workers' respiratory health. Early identification of work-related respiratory disease (WRRD) is associated with improved disease outcomes and benefits for other workers.

Respiratory health surveillance (HS) is a scheme of repeated health checks used for the early identification WRRD. Health and safety law in Great Britain requires employers to implement HS when workers remain exposed to health risks even after exposure mitigation measures have been put in place. This is because such control measures may not always be reliable, despite appropriate checking, training, and maintenance, and because disease may still occur despite very low levels of exposure.

As regulator of health and safety in workplaces in Great Britain, the Health and Safety Executive (HSE) provides advice to employers for those workplaces where agents that may cause respiratory disease are present. The principal aim of respiratory HS is early detection of WRRD and prompt action regarding the affected individual and exposed workforce. HS may also therefore help to prevent respiratory disease in unaffected individuals. However, respiratory HS is not a replacement for good exposure control, for which the main aim is primary prevention of WRRD for all exposed workers.

WRRD have varied symptom latency, clinical presentations, diagnostic tests, management, and prognosis. The frequency of respiratory HS, and variety of tools used, reflect this. The practical and cost implications of respiratory HS influence its implementation in Great Britain, where the majority of workplaces do not have access to formal providers of occupational health. The evidence-base for respiratory HS has not been reviewed systematically since 2012.

Aim

This research was commissioned by HSE and aimed to systematically review the evidence underpinning respiratory HS in relation to five *a priori* defined questions related to existing HSE guidance:

1. is there any evidence that the frequency of respiratory HS should be changed (from the approach currently adopted in Great Britain)?
2. is there any evidence that the techniques (mostly using questionnaires and lung function testing) used for respiratory HS should be changed?
3. does either the frequency of, or the technique used, for respiratory HS vary depending on the disease being considered (e.g., questionnaire and/or lung function testing for occupational asthma)?
4. should the type of HS vary by the hazard e.g., flour vs isocyanates?
5. what are the knowledge gaps or conflicting evidence in relation to HS to inform the future needs of HSE's health strategy to prevent work-related lung diseases?

Methods

A literature search was undertaken using Web of Science and combined Medline and Embase on the OVID platform databases to identify the relevant peer-reviewed scientific literature from 2012 onwards. Potentially relevant earlier studies were identified from a 2012 review paper. The final review includes 86 primary research and review papers. This review was conducted to PRISMA guidelines and registered with PROSPERO (CRD42021225759). Due to the heterogeneity of studies, including differences in the primary research question in the conceptualisation, definition, and measurement of respiratory HS, it was decided not to formally assess study quality, although the lack of a single randomised controlled study evaluating health surveillance suggests that the overall quality of evidence is not high. Evidence synthesis was structured around relevant specific diseases or exposures and so followed the synthesis without meta-analysis guidelines.

Results

Findings detailed in this report include:

- the included studies were heterogenous. Most were cross-sectional, there were few cohort studies and no randomised-controlled trials
- evidence on the effectiveness of HS was lacking, with few studies conducted evaluating the impact of HS holistically. Most studies looked at the contribution of HS to earlier diagnosis. Secondary health effects, effects on other exposed workers, barriers to implementation, and costs were not commonly explored
- there was no evidence to support changes in the frequency of or tools used for respiratory HS. Further research is needed to evaluate the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness
- occupational asthma (OA) and accelerated silicosis were identified as conditions of particular concern given their impact on working populations and potential for significant harm. Employers should be aware of the risk of these conditions and their legal obligations to protect workers, particularly in implementation of respiratory HS and prompt action on its findings
- most studies in OA conducted respiratory HS more frequently in the first two years of exposure, where the risk of developing the condition is highest. Frequency of HS after this lacks evidence and requires further study
- techniques for respiratory HS varied between studies. Respiratory health questionnaires and spirometry were the most used tools. The sensitivity and specificity of both approaches vary according to the condition being surveyed, the subject, equipment available, and operator performance. These factors should be considered when interpreting results and early referral to specialists in occupational lung disease encouraged if there is a suspicion of WRRD

- questionnaires and spirometry are low cost and deliverable in workplaces. They will continue to form an important part of HS for WRRS
- there was no specific evidence to support a change in immunological testing in respiratory HS. The use of skin prick testing and/or specific immunoglobulin E (IgE) is useful for determining sensitisation to high molecular weight allergens such as laboratory animals, wheat, and flour enzymes, and also to platinum salts
- there was no evidence to support a change in radiological testing in respiratory HS. Further evidence is needed to support the use of high-resolution and/or low-dose computed tomography (CT) scanning as an alternative or adjunct to chest radiography for silicosis, other pneumoconioses, and lung cancer
- there was insufficient evidence to suggest that the types of health surveillance, for a given health outcome, should vary substantially by the type of hazard. However, it is expected that HS frequency and tools will vary depending on the WRRD under surveillance, and workplaces may utilise multiple HS tools or programmes where workers are at risk of more than one WRRD
- there are significant knowledge gaps in respiratory HS, and future research strategies should focus on:
    - identifying workers at risk of specific WRRD and consideration of tailored respiratory HS for these individuals
    - improving the reliability of questionnaires and spirometry in the surveillance of WRRD, including trigger points for action on lung function decline
    - understanding the use of other biomarkers (fractional exhaled nitric oxide, exhaled breath, urine, blood, pleural fluid) as tools to monitor harmful exposures and in WRRD surveillance
    - the use of CT and other radiological tests in the surveillance of WRRD (particularly in early detection for accelerated silicosis and lung cancer)
    - the use of immunological testing for surveillance of WRRD, including understanding relationships between sensitisation and development of disease or where mechanisms of sensitisation are unclear

Conclusions

The review found no evidence to support changes in HSE's guidance on respiratory HS. There was no evidence to support changes in the frequency of or tools used for respiratory HS. However, further research is needed to evaluate the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness.

Future research programmes should also continue to raise awareness of the risks of WRRD among employers, employees, healthcare professionals, and the general public.

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1. Introduction

The Health and Safety Executive (HSE) defines HS as a scheme of repeated health checks which are used to identify ill health caused by work. Hazards which require HS include noise, vibration, and substances hazardous to health, including respiratory health. Health and Safety law requires HS when workers remain exposed to health risks even after controls have been put in place, because control measures may not always be reliable, despite appropriate checking, training and maintenance (https://www.hse.gov.uk/health-surveillance). Responsibility for determining the need for respiratory HS lies with the employer, and where appropriate the employer should seek competent advice from an occupational health provider. HS should be part of an overall risk management programme, and not be used as a substitute for risk assessment or implementing appropriate control measures.

There are an estimated 12,000 new deaths annually related to occupational lung disease (OLD) in the UK alone (1). Additionally, there an estimated 19,000 new cases of breathing conditions related to exposures in the past year, and an estimated149,000 new or longstanding breathing conditions attributed to work. Respiratory HS aims to reduce this burden and is the focus of this review. Respiratory HS is important for:

- detecting respiratory ill-health effects at an early stage, so appropriate actions can be taken to prevent further harm and protect workers, for example leading to increased detection of pre-clinical silicosis in workers exposed to high levels of crystalline silica in Victoria, Australia (2)
- providing evidence of the effectiveness of workplace control measures and show whether the risk assessment and/or any controls need to be reviewed and revised, for example leading to reviewing of risk assessments following an outbreak of obliterative bronchiolitis related to diacetyl in California (3)
- enabling employees to raise concerns about how work affects their respiratory health
- providing an opportunity to reinforce training and education of employees (e.g., on the impact of respiratory health effects and the use of personal protective equipment)

Examples of occupational exposures and circumstances or occupations that might need respiratory HS are:

- asthmagens: isocyanates, flour dust, grain dust, glutaraldehyde, wood dust, latex, rosin-cored solder fume, laboratory animals, glues, and resins
- exposure to respirable crystalline silica as a cause of silicosis
- exposure to asbestos as a cause of asbestosis
- agents that can cause chronic obstructive pulmonary disease: e.g., chemicals fumes and dusts

- agents that can cause respiratory conditions such as hypersensitivity pneumonitis, and obliterative bronchiolitis

Previous reviews of HS have concluded that the timing and tools of implementation vary, and there is limited evidence base for their use. Fishwick and Forman suggested that questionnaires remain a key component of respiratory HS although they may have limited sensitivity and specificity for early detection of occupational asthma (4). Their review also suggested that lung function testing was recommended for higher-level health surveillance for occupational asthma (that is, where there is at least a moderate risk of exposure to an agent or agents known to cause asthma). However, others have suggested that spirometry does not appear to contribute to the detection of new cases of occupational asthma (5), whilst some have developed approaches to predict sensitisation to flour and animal laboratory allergens using simple questionnaires (2, 6). In their review of HS for OA in the UK, Fishwick et al. (3) concluded that its uptake is generally low, in particular, in smaller enterprises, and only around 20% of UK workplaces have access to occupational health.

In order to support and underpin their ongoing occupational health strategy, HSE requested an updated review of the literature to determine the evidence on the effectiveness of respiratory HS. In particular, this review aimed to address the following research questions:

1. is there any evidence that the frequency of respiratory HS in HSE's guidance should be changed?
2. is there any evidence that the recommendation in HSE's guidance regarding the techniques (mostly using questionnaires and lung function testing) that should be used for respiratory HS should be changed?
3. does either the frequency of, or the technique used, for respiratory HS vary depending on the disease being considered e.g., questionnaire and/or lung function testing for occupational asthma?
4. should the type of HS vary by the hazard e.g., flour vs isocyanates?
5. what are the knowledge gaps or conflicting evidence in relation to HS to inform the future needs of HSE's health strategy to prevent work-related lung disease?

This report describes the results of this systematic review.

2. Methods

2.1 Search strategy

A systematic literature search was conducted to identify the literature evaluating the current methods and frequency of their use for occupational respiratory HS. The earlier review conducted by Lewis and Fishwick (2013) (7) had identified the evidence related to respiratory HS from literature published prior to 2013. To follow on from their search, the new literature searched on occupational respiratory HS covering the time period Jan 2012 to Jan 2021. In addition, the literature identified by Lewis and Fishwick was included, where it met the inclusion criteria. Lewis and Fishwick (2013) (7) reported that searches of other databases did not identify relevant documents that had not already been identified by the main database. Therefore, searches of other databases including NIOSHTIC, HSELINE and OpenGrey were not carried out for this review. In addition, manual searches were carried out for relevant studies cited by articles included in this review. Finally, several researchers and regulators in the US, South Africa, Australia, and Europe were contacted who had expertise in respiratory HS to determine the evidence base known to them.

The literature review was conducted following the PRISMA guidelines (8) and registered with PROSPERO (9).

2.2 Definitions and search terms

To ensure that the search strategy was comprehensive, preliminary searches focused on identifying search terms that returned the largest proportion of articles referenced in Lewis and Fishwick (7). Through consultation with a University of Manchester librarian, the key terms were expanded in order to refine the search strategy. Search terms within themes were incorporated together using the “OR” Boolean operator. The “AND” Boolean operator was used to combine the three concepts related to HS, work, and respiratory disease.

A search in Web of Science and a combined Embase and Medline search in the OVID platform were carried out on 20th January 2021 using the following search terms:

> (occupation* OR work* OR employ*)
>
> AND
>
> (pulmonary OR chest OR lung OR respiratory OR pleura*)
>
> AND
>
> ((health OR medical OR respiratory) NEAR/3 (survey* OR surveillance OR monitor* OR question* OR assessment* OR test* OR screen*)).

The full search strategy for Web of Science and OVID is presented in Appendix 1.

2.3 Selection criteria

To be included in the review, part of the rationale or discussion/conclusions of the paper included a specific mention (at least some form) of respiratory HS or an equivalent term. The following types of study were considered eligible for inclusion in our review:

1. studies published after 2012 or included in Lewis & Fishwick (7)
2. epidemiological studies assessing prevalence or incidence of respiratory disease AND discussing implications for HS
3. epidemiological studies evaluating any methods for early (subclinical) detection of respiratory disease in the context of respiratory HS
4. epidemiological studies assessing the prevalence or incidence of respiratory disease based on a respiratory HS programme
5. studies evaluating the efficacy, effectiveness, or efficiency (including quality) of a respiratory HS programme
6. studies evaluating the effectiveness of respiratory HS in general.
7. studies reviewing guidance for respiratory HS
8. studies concerned with non-communicable respiratory disease(s)

The following types of study were excluded:

1. papers published before 2013, unless cited in Lewis & Fishwick (7)
2. epidemiological studies assessing prevalence or incidence of respiratory disease, but without discussion of implications for respiratory HS
3. studies that made only a passing reference to HS in the conclusion (i.e., it was mentioned as a recommendation)
4. studies where the health outcome was not respiratory disease
5. publications not in the English language
6. conference abstracts
7. studies of children and former workers not currently exposed to occupational respiratory agent(s)
8. activities relating to an occupational activity that is illegal in the UK (e.g., growing of cannabis plants)
9. studies that evaluated any clinical techniques for diagnosis of respiratory disease, but not in the context of respiratory HS
10. studies related to communicable disease(s), such as tuberculosis and legionella

Table 1 provides some further details, domains and health conditions that were included in the literature review.

Table 1 Details of Respiratory HS literature review

Condition or domain being studied	Early detection of work related non communicable respiratory diseases.
Participants / population	Workers potentially exposed to agents in the workplace that could damage their respiratory health.
Intervention	Respiratory HS.
Comparator	Where present, population not under respiratory HS or where the respiratory health surveillance is lower level (as defined by Lewis and Fishwick (7)).
Main outcome(s):	Respiratory health outcomes (quantitative where possible). These could include asthma, silicosis, pneumoconiosis, lung cancer, bronchitis, emphysema, chronic obstructive pulmonary disease (COPD), asbestosis, allergies, and mesothelioma and related conditions.
Surveillance Tools	Symptom questionnaires, chest x-rays, lung function testing (spirometry) and immunological tests. Could include additional techniques if the search uncovered them.

2.4 Screening and data extraction

The results of the literature searching were uploaded to Covidence software (https://www.covidence.org/), which was used to screen the titles/abstracts and full text articles. Four reviewers (DMM, SD, IYKI and LB) piloted the title/abstract screening process, by independently screening 50 title/abstracts with uncertainties being resolved through discussion. Once consensus was achieved, three reviewers (SD, IYKI and LB) independently screened the remaining abstracts and full text, with any further uncertainties resolved through discussion and referral to a fourth reviewer (DMM, MvT) if necessary.

Four reviewers (DMM, SD, IYKI and LB) extracted data from a random sample of five articles using a pilot form, and any necessary modifications were made subsequently.

The remaining articles were distributed to the four reviewers and data were extracted using a standardised form. The data extracted included the following:

1. first author and publication year
2. study aim(s) and objectives
3. study type e.g., cross-sectional epidemiological study, review of a HS programme, review of HS, or review of HS guidance
4. setting: population studied (including sample size)

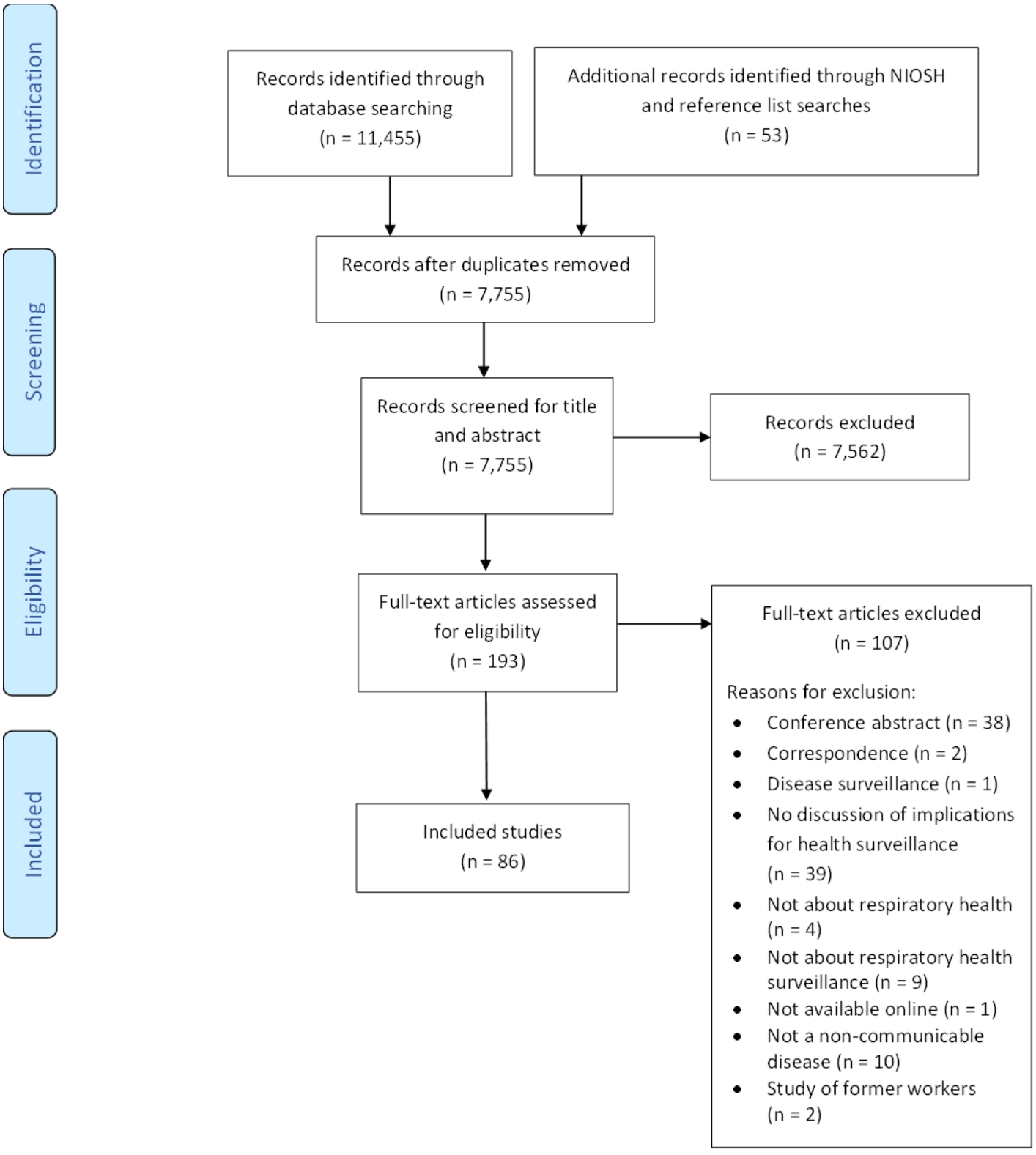
5. exposure of interest
6. respiratory health outcome(s) of interest
7. HS intervention(s), eg symptom questionnaire, spirometry, etc.
8. results related to their effectiveness with focus on sensitivity and specificity (and related measures) for early detection of disease - both quantitative and qualitative results were included
9. evidence provided by the study related to research questions set out in the Introduction
10. conclusions made in relation to respiratory HS

The results of the data extraction were set out in results tables, where missing data were recorded as blank entries, and the evidence synthesised using the synthesis without meta-analysis (SWiM) guidelines (10), in which the evidence was synthesised by respiratory health outcome.

3. Results

In the initial electronic database searches, 11,455 publications were identified. After removing duplicates, 7,702 publications remained. Fifty-four additional publications were identified by manual search and other sources including via the correspondence. A total of 7,562 publications were excluded following title and/or abstract screening, leaving 193 publications for full text screening. Of these, 86 papers were included. See PRISMA diagram for details of the screening process (Figure 1).

Figure 1: PRISMA diagram of the screening process



3.1 Occupational asthma and occupational allergic diseases

There were 44 studies related to work-related respiratory symptoms, OA, and other occupational allergic diseases, making this the most studied disease category (Table 2). The publication years for the studies ranged from 1996 to 2020. Most were cross-sectional, with three longitudinal studies and ten review articles included. Thirty-two studies wholly or partially addressed HS specifically: the remainder concerned strategies used for the diagnosis of respiratory disease in workplaces (therefore applicable to respiratory HS).

The appraised evidence was lacking in detail with regard to the tool, frequency, and effectiveness of health surveillance of occupational asthma.

Where specified, the hazards considered in the publications included isocyanates, flour and grain dust, laboratory animal allergens, enzymes, platinum salts, seafood allergens, welding fumes, and other general asthmagens including non-specific dust. Included studies considered specific occupations such bakers, hairdressers, compost workers, welders, farmers, professional divers, US military, municipal police employees, and aluminium potroom workers.

Almost all of the papers described the use of respiratory health questionnaires; the three exceptions were two reviews article on the utility of fractional exhaled nitric oxide (FeNO) and other biomarkers in OA HS and diagnosis (11), and an article prescribing a model to estimate the cost-effectiveness of HS for occupational asthma (12). The majority of publications also considered spirometry, including some that used bronchoprovocation or bronchodilation procedures. Immunological testing (including specific IgE, skin prick test, or radioallergosorbent (RAST)) was considered in 23 publications, while ten considered biomarkers such as FeNO and sputum eosinophils. Two papers reported on diagnostic models used for identifying at risk workers.

Several papers reported on the utility of questionnaires, suggesting they lack sensitivity and specificity for diagnosis, and may underestimate the prevalence of OA in exposed populations (4, 13-17).However, there was consistent agreement among papers that since questionnaires are simple to perform and inexpensive, they are likely to continue to form an important part of respiratory HS. Changes to questionnaires to improve their sensitivity and specificity (including questions on work-relatedness) (18),or standardising questionnaires (19), were recommended. One paper suggested using questionnaire data to refine diagnostic models to predict the development of asthma in exposed workers (6). It was suggested that such questionnaire-based diagnostic models can be useful for determining which workers may need further clinical examination and which may not (20).

Several studies reported on lung function testing, including spirometry, FeNO, measures of small and medium-sized airway resistance (FEF 25-75), and non-specific bronchial hyperresponsiveness (NSBHR). Several papers reported a lack of sensitivity and/or specificity for spirometry in diagnosing OA (5, 15, 20-22). Factors affecting sensitivity and

specificity included use of a single test (rather than serial testing), the timing of the test (for example when an individual is asymptomatic or not exposed), and the lack of baseline testing with which to compare current results. However, spirometry was reported to be more sensitive than a questionnaire alone in diagnosing OA (23). Improvements in spirometry were suggested by undertaking serial measurements and using clearly defined thresholds for interpretation of change (7) and having baseline comparative data (22).

There was no consistent evidence to support the use of FeNO in respiratory HS for OA. One paper reported FeNO may be useful in diagnosing eosinophilic asthma caused by exposure to high molecular weight asthmagens and isocyanates but did not report evidence for non-eosinophilic OA or other agents (11). FeNO was also explored in professional divers (24) and bakers and hairdressers (15). In bakers and hairdressers FeNO and spirometry gave differing (and potentially complementary) information on OA risk, and the authors suggested including sputum eosinophil count as and additional measure of airway inflammation, although it was acknowledged that practical application of this was limited (15). Several studies highlighted that FeNO is non-specific, may be affected by many other factors, and has a high false positive rate, suggesting its utility should be better understood before widespread use is recommended (7, 18, 19).

One study of firefighters suggested that abnormalities in FEF 25-75 may indicate the development of chronic obstructive changes, and that changes in this measure represent the earliest signs of obstructive airways disease, prior to symptoms or the onset of abnormal spirometry (25). However, the study also highlighted that these measures are more variable and longitudinal interpretation is challenging. One study reported on NSBHR in respiratory HS (20). The positive predictive value of NSBHR was lacking as a predictive tool for occupational asthma (20).

There was no consistent evidence to support the use of immunological testing in respiratory HS. Several studies reported that skin prick test and/or specific serum IgE measures may be useful for a number of allergens, including various high molecular weight allergens (14, 19, 20) and platinum salts (7, 18, 26). Limitations to immunological testing include the chance of sensitisation in the absence of disease, and the importance of use in conjunction with questionnaires and lung function (2); the lack of sensitive tests for low molecular weight allergens (27); and the need for better understanding of their utility before widespread use (7).

In a review of HS for occupational asthma it was suggested that there is little evidence that HS is used strategically to reduce asthma incidence (18) and in a review of methods for the prevention of occupational asthma there remains a shortage of published evidence that will encourage those involved to use it more efficiently (14). Slightly more encouragingly, in a review of the practical implications for occupational physicians on the prevention of asthma, it was suggested that respiratory HS has been associated with improved health outcomes, but that further studies are required to understand the optimum

frequency and measures for such programmes and to identify the separate contributions of the components (28).

Table 2: Occupational Asthma and Occupational allergic diseases

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Al-Batanony et al. 2012 (21)	Workers in a bone glue factory (n=50) and unexposed workers' relatives (n=50)	Toluene di-isocyanates	Questionnaire on personal and occupational histories Spirometry	N	To study some respiratory and neurological disorders that may arise in workers in a bone glue factory	Spirometry should be included in periodic medical examinations
Allan et al. 2010 (5)	People who work with laboratory animals (n = 85)	Laboratory animal allergens	Survey results compared against review of surveillance symptom questionnaires. Audit of validity of surveillance spirometry (FEV1, FVC, % predicted reference group values) Further investigations	Y	To evaluate the efficacy of a respiratory HS programme	Current surveillance appears effective in identifying potential cases of occupational asthma
Basketter et al. 2015 (29)	Detergent industry workers exposed to enzyme proteins in formulated products.	Enzymes	Health questionnaire, including respiratory allergies. Lung function test Skin prick test, IgE	Y	Practical implementation of industry guidelines on approaches to HS was examined	Regular surveillance of the health of the potentially exposed workforce is required to give assurance of a safe working environment
Baur et al. 2012a (30) (Review)	N/A	Asthmagens	Questionnaires that identify symptoms of wheeze and/or shortness of breath Non-specific bronchial hyper-responsiveness (NSBHE) to methacholine or histamine Serial peak flow measurements Pre- to post-shift changes in lung function	Y	To present the management and prevention options for work-related asthma and their effectiveness	A stratified surveillance programme should be applied to at-risk workers

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
			Changes in NSBHR at and away from work alone Skin-prick and specific IgE measurements Carefully controlled specific inhalation challenge tests Sputum eosinophils Fractional exhaled nitric oxide (FeNO)			
Baur et al. 2012b (31) (Review)	N/A	Asthmagens	Sensitisation and individual susceptibility Questionnaires Skin-pricks tests Measurement of specific serum IgE antibodies	Y	Medical screening and surveillance, one of 5 key questions	A stratified medical screening strategy and surveillance programme should be applied to at-risk workers
Brant et al. 2005 (16)	Around 3000 bakery employees	Flour dust and enzymes	Short questionnaire on respiratory symptoms Questionnaire on work-relatedness Serum IgE for wheat flour and fungal α-amylase	Y	To estimate how accurate routine workplace HS is at estimating the prevalence of occupational asthma	Routine surveillance can underestimate the workplace burden of disease
Cassidy et al. 2017 (23)	Three U.S. plants (with an estimated eligible workforce of 300) participated between 2006 and 2012. Eligible workers were those who performed tasks with potential TDI exposure (n = 197)	Toluene di-isocyanate	Spirometry Questionnaire Further questionnaire when positive response to trigger questions and/or 10% annual decline in FEV	Y	To describe a study of medical monitoring methods and lessons learning in detecting health outcomes in US plants producing toluene diisocyanate (TDI)	Medical monitoring of TDI workers identified workers triggering further assessment per study protocol

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
			Medical evaluation to assess asthma: Bronchodilator test, Methacholine challenge and Reviewed by external expert pulmonologist consultant			
Coman & Lemiere, 2017 (11)	N/R	High molecular weight allergens; low molecular weight allergens	Fractional exhaled nitric oxide	Y	To review recent studies and advancements regarding the use of FeNO during screening and investigating potential causes of asthma	Further studies still required to clarify the role of FeNO in screening of occupational asthma
Deacon & Paddle 1998 (32)	Manufacture of grain-based foods (n = 570)	Gain dust, four dust and fungal amylase	Questionnaire for health symptoms Spirometry	N	To assess the presence of work-related respiratory symptoms and impaired ventilator performance in male employees manufacturing grain-based breakfast foods	It appears current exposure limits for grain, flour, food ingredients and cooked food dusts are adequate to protect workers against impairment of ventilator performance
Fishwick & Forman 2018 (4) (Review)	N/A	N/A	Questionnaires Lung function testing (FEV1 and FVC) Immunological testing Fractional exhaled nitric oxide Sputum eosinophilia Exhaled breath condensate	Y	To assess the current approaches to health surveillance for occupational asthma	Despite its role in identifying causes of occupational asthma early, its uptake and quality have significant room for improvement

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Gannon et al. 2005 (27)	Company employees from >70 countries manufacturing a wide range of products	Isocyanates in the manufacture of polyurethane foams, plastics, coating, and adhesives.	Questionnaire Spirometry	Y	To describe an isocyanate occupational asthma prevention programme	The surveillance programme for isocyanates has several important components
Gordon et al. 1997 (13)	Flour-exposed workers in a large bakery (n = 362)	Flour dust	Questionnaire for health symptoms Attendance records, sick notes, and direct workplace observations Clinical assessment Spirometry (FEV1 and FVC), serial peak expiratory flow rate (PEFR) analysis Radioallergosorbent testing (RAST) for specific IgE.	Y	Compared questionnaire screening with other methods detecting workers with asthmatic symptoms	Survey questionnaires may underestimate the prevalence of asthma symptoms
Harris-Roberts et al. 2012 (33)	44 workers participated (44 workers completed the questionnaire and 39 gave blood samples)	Workplace allergens (prepared from dyed cotton and two types of latex braids collected from the workplace) and commercial latex extract (Allergopharma Joachim Ganzer KG, Reinbek, Germany, including Hev b1, Hev b3, Hev b5, and Hev b6.02).	Questionnaire Blood samples (IgE testing) Spirometry	Y	To assess symptoms and sensitisation to latex in a group of workers employed in a latex-braiding workplace using both standard and bespoke methods	Allergy testing identified clinically significant cases of work-related respiratory symptoms that would otherwise have not been identified or misattributed to an irritant or other response
Jeebhay & Baatjies 2020 (19) (Review)	N/A	Wheat and flour dust	Respiratory health questionnaires Immunological testing (specific IgE, skin prick tests)	Y	Focus on recent studies on the prevention of bakers' asthma, including reference to medical surveillance	Future studies need to focus on the development of standardised respiratory questionnaires of

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
			Fractional exhaled nitric oxide (FeNO) Spirometry Sputum eosinophilia Exhaled breath condensate			occupational asthma and rhinitis surveillance
Kraw & Tarlo 1999 (34)	Workers manufacturing polyurethane foam (n = 150-250 over a 6-year period, 39 referred)	Toluene di-isocyanate and diphenylmethylene di-isocyanate	Questionnaire Spirometry (change of 15% from baseline)	Y	To evaluate the efficacy of workplace surveillance in detecting cases of occupational asthma	The study did not show clear benefit from the addition of spirometry to a respiratory questionnaire in a surveillance programme of isocyanate-induced occupational asthma
Labrecque et al. 2011 (35)	Workers who were participants in the Provincial Occupational Health Network medical surveillance programme (n = 2897) between July 00 and Dec 04. A control group of workers diagnosed with occupational asthma due to di-isocyanate between 95 and 04 who did not participate in the medical surveillance programme	Di-isocyanate	Questionnaire Spirometry (before and after bronchodilator administration) Bronchoprovocation test	N	To compare the severity and cost of diisocyanate-induced occupational asthma in workers participating in a surveillance programme with those being referred by their physician	Subjects with occupational asthma screened by a medical surveillance programme had a better outcome both at time of diagnosis and 2 years after removal from exposure, with lower compensation costs compared to controls

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Lewis & Fishwick 2013 (7) (Review)	N/A	Silica, agents causing COPD, agents causing asthma, agents causing other lung diseases	Respiratory health questionnaire Lung function (absolute and percentage predicted FEV1 and FVC). Cross-sectional measures of FEV1 and FVC within shift changes, longitudinal changes, FEV1/FVC < 5th percentile (as a definition of COPD) and standardised residual of the FEV1 < 1. Radiological abnormality Immunology Bronchial hyper-responsiveness Fractional exhaled nitric oxide	Y	To identify areas of good practice with respiratory HS and to formulate recommendations for practice.	A standard validated questionnaire with associated guidance should be developed
Lucas et al. 2016 (36)	N/A	Respiratory seafood allergens and/or Sea products (crustaceans, Molluscs, inhalation of wet aerosols in fish processing workers and fishmongers, salmon, turbot, trout, worms, preservatives such as Sodium metabisulphite)	Questionnaire Clinical examination If signs of allergy or every 4 years: Spirometry Skin prick test RAST Bronchoprovocation test	N	To provide an update on occupational asthma in the maritime context and provide recommendations about medical surveillance	Medical surveillance should detect first symptoms or clinical signs of occupational asthma or rhinitis
Lund et al. 2000 (37)	196 male subjects	Working in a potroom at an aluminium smelter	Questionnaire Spirometry Measurement of nitric oxide	Y	To examine whether platinum plant workers exposed to potroom pollutants would have higher concentrations of NO in expired air than control	Exposure to potroom pollutants is associated with increased concentrations of

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
					subjects at the same plant but working outside the potroom	exhaled NO in non-smoking subjects and so may be a markers of early airway inflammation
Mackie et al. 2008 (38)	3,700 employees underwent surveillance each year	Di-isocyanates from spray painting and panel beating	Questionnaire Spirometry (FVC, FEV1, FER) Bronchial challenge testing	Y	To assess the efficacy of a UK-wide HS programme provided to the motor vehicle repair industry	HS is only one part of a process for identifying occupational asthma
Martini et al. 2012 (24)	Professional divers from the Italian National Fire Services Department between November 2009 and February 2010 (n = 74)	Pro-inflammatory pollutants	Questionnaire Spirometry Fractional exhaled nitric oxide (FeNO)	Y	To examine airway inflammation using FeNO in HS programmes	Divers with high FeNO should be scheduled for further clinical-instrumental investigation and laboratory tests to make sure they have no diving contraindications.
Meijer et al. 2004 (6)	Laboratory animal workers (n = 351)	Laboratory animals	Questionnaire Spirometry Skin prick testing	Y	To develop a HS strategy to detect and predict occupational allergic disease efficiently	The risk of (future) sensitisation and severity of laboratory animal allergy can be predicted accurately with diagnostic and prediction models based on questionnaire items
Meijer et al. 2010 (2)	Bakers at high risk of having work-related allergy were identified by use of a questionnaire-based prediction model for	High-molecular-weight flour allergens	Questionnaire Model predicting the individual probability of sensitisation to wheat and/or fungal a-amylase allergens	Y	Performance of a prediction model in bakers who participated in a HS programme and validation study	Procedure appeared effective in detecting work-related allergy among bakers

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
	work-related sensitisation. The short questionnaire was completed by 5325 bakers. Performance of the model was evaluated in n = 674 randomly selected bakers who participated in the medical surveillance programme and the validation study					
Merget et al. 2001 (39)	159 catalyst production workers (50 craftsmen and 66 control subjects)	Platinum (Pt) salts	Skin prick test) Questionnaires/physician interview Total serum IgE levels Spirometry Bronchial responsiveness to histamine	Y	To assess the effectiveness of a medical surveillance programme in workers exposed to platinum salts	This study proves the effectiveness of a medical surveillance programme for the prevention of occupational asthma from platinum salts
Merget et al. 2017 (26)	96 workers with platinum salt allergy	Platinum (Pt) salts	Questionnaires/physician interview Skin prick test Spirometry Bronchoprovocation test Total IgE Inhalative challenges with Pt salts	Y	To evaluate the impact of medical surveillance to prevent occupational asthma due to platinum salts	The overall outcome of medical surveillance in catalyst production plants during the last decades is poor and so a skin prick test should be included in the primary tool

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Moghtaderi et al. 2012 (40)	Workers who were directly involved in flour processing at four wheat flour mills in Iran (n = 118).	Organic flour dusts	Questionnaire Spirometry Skin prick test	N	Study to evaluate the effect of wheat dusts on pulmonary function	Study supports conclusion that long-term exposure to wheat flour dust and airborne mite allergens can impair lung function
Paraskevaidou et al. 2019 (41)	Furniture workers (n = 83). Workers exposed to chemicals (n = 35), wood dust (n = 23) and office workers (n = 25)	Chemicals and wood dust	Respiratory health questionnaire Spirometry (pre and post bronchodilation) Peak expiratory flow rate FeNO Skin prick tests (with common allergens) Rhinomanometry Bronchoprovocation test	Y	To study the frequency of work-related asthma and rhinitis in a sample of furniture workers	The most useful tools for diagnostic screening were specific questions from the questionnaire, PEFR measurements, including days off work, with OASYS-2 score and ABC score as well as the methacholine challenge test
Rose et al. 2012 (42)	US military personnel deployed to Iraq and Afghanistan	Burn pits operating in close proximity to where troops live and work, to industrial emissions, and to PM (particulate matter) from ambient desert dust	Questionnaire Spirometry Physical readiness testing	N	To develop consensus recommendations for medical screening for lung diseases in veterans	There is a need for targeted, practical medical surveillance for lung diseases for all symptomatic deployed personnel
Smedley & Coggon 1996 (43)	Occupational health departments (n=61)	Respiratory sensitising agents (glutaraldehyde, formaldehyde, methyl methacrylate and X-ray processing chemicals, hardwood dust, isocyanates, laboratory animals)	Questionnaire Physical examination Pulmonary function testing	Y	Audit of HS for people working with respiratory sensitisers in a sample of NHS hospitals	Occupational physicians caring for hospital staff should discuss and establish guidelines for effective surveillance of people working with the commonly

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
						encountered sensitisers
Suarthana et al. 2010 (44)	Development set: Dutch bakery workers (n = 867); and external validation set: Independent Dutch bakery workers (n = 390)	Flour allergens	Questionnaire Diagnostic model for the detection of sensitization.	N	To develop and validate a prediction model to detect sensitisation to wheat allergens in bakery workers	A simple model with questionnaire items only, can be used to stratify bakers according to their risk of sensitisation to what allergens
Suojalehto et al. 2017 (45)	60 subjects with occupational asthma	Flour and grain, animal-derived proteins, cyanoacrylates, and isocyanates.	Respiratory symptoms questionnaire Spirometry Skin prick test results for common environmental allergens	Y	To assess the role of surveillance and spirometry in detecting occupational asthma and to evaluate the quality of the spirometry	Fewer than 1 in 5 occupational asthma cases were detected through medical surveillance. Our results highlight the importance of work-related nasal symptoms in detecting occupational asthma
Szram & Cullinan 2013 (18) Review	N/A	Airborne respiratory sensitising agents	Respiratory health questionnaire Spirometry Immunological testing FeNO	Y	Review of the use of HS in exposed workers	The effective . of HS for occupational asthma continues to be challenging. Useful advances could be made by greater collaboration between employers, employee organisations, legislators, and researchers

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Tarlo & Liss 2005 (28) (Review)	N/A	Various	Questionnaire Spirometry Skin prick test	Y	Review of studies which have assessed primary, secondary, and tertiary measures in preventing occupational asthma	Further studies needed to understand optimum frequencies and measures for medical HS programmes
Tarlo & Liss 2010 (14) (Review)	N/A	Various	Questionnaire Spirometry Immunological testing	Y	Review of prevention of sensitised-induced occupational asthma	Most secondary programmes consist of periodic respiratory questionnaire, immunologic testing when feasible (skin test or in vitro assay), and spirometry
Vimercati et al. 2015 (46)	Municipal Police employees: traffic wardens (n = 111) and a control group of administrative employees (n = 101).	Environmental pollutants	Allergological questionnaire Physical examination Spirometry specific IgE and Skin Prick Test Nasal cytology and Nasal Provocation Test (NPT)	N	To verify individual sensitisation to airborne allergens in workers with occupational exposure to environmental pollutants	Further studies are required to better understand and define the role of urban pollution in inducing allergic respiratory diseases
Wild et al. 2005 (12)	Theoretical population of isocyanate exposed workers	Di-isocyanates		Y	Study to evaluate the costs and benefits of surveillance from an employer and a societal perspective	The analysis demonstrated the value of a model-based approach to evaluate the cost-effectiveness of surveillance programmes
Wilken et al. 2012 (20)	N/A	N/A	Questionnaire Specific IgE, Skin prick test	Y	To evaluate on the basis of the available literature the	A stratified approach can increase the effectiveness and

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
(Review)			Specific inhalation challenge test		usefulness of medical screening and surveillance	reduce the costs for such programmes
Basu et al. 2018 (47)	Compost workers (n = 111) in 6 medium to large sized composting companies in the UK between July 2015 and July 2016	Bioaerosols	Questionnaire	Y	To devise, implement and evaluate a health questionnaire to detect early symptoms of occupational illness related to bioaerosol exposure	The predictive value of the questionnaire in identifying cases of occupational illness should be established
Bohadana et al. 2011 (15)	Apprentice bakers (n = 59) and apprentice hairdressers (n = 67)	Flour dust; hairdressing chemicals (persulphates)	Questionnaire for chest symptoms FeNO measures using ATS/EES recommendations. Spirometry (FVC, FEV1) - abnormal if FEV1/FVC <5th percentile of normal according to ATS/ERS recommendations	Y	To improve the performance of FeNo and spirometry for HS of apprentice bakers and apprentice hairdressers	FeNO and spirometry were not overlapping in apprentice bakers and hairdressers.FeNO may provide added information on airway inflammation not provided by spirometry though not sufficiently enough to recommend inclusion in HS programmes
Jonsson et al. 2015 (48)	Mild steel welders (n = 106)	Welding fumes/ particles	Skin prick test Spirometry Diary of symptoms Methacholine test	N	In a panel of mild steel welders aim to follow diary-registered symptoms from eyes and airways and relate them to different exposures	The results add to the evidence that welders should be offered regular medical surveillance from early in their careers
Lipinska-Ojrzanowska et al. 2017 (49) (Review)	n/a	n/a	Biochemical and cellular composition of nasal lavage fluid, induced sputum or bronchoalveolar lavage Eosinophilic inflammation in induced sputum	N	To summarise the utility of biomarker determination in work-related diseases in a recent clinical approach	A large amount research has been carried out on occupational asthma and resulted in indicating the cellular assessment of

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
			Eosinophil cationic protein FeNO before and after work-shift or SIC 8-iso-prostaglandin in FeNO Measurements of nasal nitric oxide and non-specific nasal hyper-responsiveness with histamine/methacholine or cold air testing. Neutrophilic inflammation in induced sputum			induced sputum as the most useful in the diagnostic process
Oppliger et al. 2017 (50)	Eligible workers were recruited from university units in which exposure to rats and/or mice, occurrence of respiratory and/or skin symptoms, and/or a history of animal bites reported (n = 177)	A range of animals besides laboratory mice and rats - endotoxin, irritants, and allergens	Clinical examination Spirometry IgE testing	Y	The relative risk of endotoxin, irritants, and allergens in symptom generation was assessed for updating preventive measures and HS	HS programmes need to be adapted to include a larger range of allergens and pay more attention to irritants
Senthilselvan et al. 1996 (51)	1,211 grain elevator workers	Grain dust	Questionnaire Pulmonary function tests	N	To investigate the relationship between annual change in lung function and symptoms among grain elevators who participate a surveillance programme once every 3 years	Grain elevator workers with persistent wheeze had the great annual rate changes in FEV_1 and FVC
Weissman et al. 2014 (22) (Review)		Various	Questionnaire Pulmonary function tests Imaging	N	Review of medical surveillance	Medical surveillance is a useful tool in assessing emerging occupational and environmental respiratory diseases

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
						by facilitating improvements in primary prevention and enabling to help individuals through secondary prevention

3.2 Obstructive airways disease

Airflow obstruction is diagnosed when the ratio of the volume of air expelled by the lungs in a forced expiratory manoeuvre in 1 second (FEV_1) divided by the volume of air forced out of the lungs in the same manoeuvre (Forced Vital Capacity, FVC) is less than 0.7 or the lower limit of normal (LLN) ((52). There were 15 studies that examined obstructive airway diseases including COPD, asthma, and asthma and obliterative bronchiolitis (OB). (Table 3).

The publication years for the studies ranged from 2001 to 2020. Four studies evaluated single HS approaches while two studies evaluated wider HS programmes; most studies were cross-sectional (n=8) with one longitudinal study. The studies in COPD and asthma included road sweepers exposed to dust, endotoxin exposure from metal-working fluids in machine manufacturing, military personnel with exposure to burn pits, industrial fires and desert storms, farmers, foundry workers, firefighters, nanomaterials manufacture, workers in concrete, rubber, and paper industries. Two studies looked at OB in diacetyl exposure in flavour manufacturing workers. One review investigated the risk factors associated with occupational COPD, and one study compared spirometric parameters.

Most studies used questionnaires to assist HS and diagnosis. Questionnaires were important for detecting symptoms in workers at risk of obstructive airways disease including wheeze (53), cough and phlegm. Standardised and validated questionnaires for respiratory HS and COPD are lacking (7, 54).

The use of spirometry was highlighted as important in one study, which also emphasised the benefit of serial over single measures and the importance of declines within normal ranges (53). Several limiting factors in spirometry were reported in a review of COPD: variability in the consistency of delivery and training for spirometry in occupational settings; the optimum metric used for detecting significant changes in spirometry; and the optimum threshold for detecting significant changes in longitudinal lung function that should prompt specialist referral (54). In a study of military personnel, it was noted that for some occupations where physical fitness is important, such working populations may have supranormal values for lung function (42). Interestingly, a cross-sectional study of subjects referred for occupational health evaluations determined that FEV_6 and FEV_6/FVC showed acceptable accuracy for the diagnosis of restrictive and obstructive lung diseases (55), although a study in dairy farmers suggested its diagnostic performance depended on how well practitioners were trained (56).

Spirometry was regarded as the single most important, as well as simplest, cheapest non-invasive technique for aiding detection of pre-clinical disease in a study of road sweepers (57). Serial spirometry is important, and attention should be given to declines even within normal ranges (53, 58). Development of prognostic screening tools may help to target

groups at risk for obstructive airways disease who may require enhanced surveillance (59).

Table 3: Obstructive airway diseases

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Anwar et al. 2013 (60)	Exposed group (n=100); Unexposed group (n=100)	Roadside dust	Chest radiograph Spirometry Respiratory symptoms assessment	Y	To investigate the role of spirometry in the preclinical diagnosis of airway obstruction	Spirometry is the simplest non-invasive technique to detect preclinical disease
Cummings et al. 20202 (53)	388 workers at baseline, 250 workers at a follow-up 3.5 years later.	Endotoxins (from in-use metalworking fluid)	Questionnaire Spirometry	N	To determine the additional cases of BADE that could have occurred at a facility and if the risk was ongoing	Additional cases of BADE merit investigation, including spirometric surveillance of co-workers, to better understand aetiology and prevent disease.
Fishwick et al. 2015 (54) Review	n/a	Risk factors for the development of COPD	Questionnaire Lung function	Y	To provide a standard of care for the identification of COPD	Early identification of COPD can be achieved by a combination of a respiratory questionnaire and accurate lung function assessment

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Jan et al. 2020 (56)	During the time period 2012-2017, randomly selected dairy farmers in Brittany (France) (n = 1203)	Not reported	COPD assessment Test (CAT) Questionnaire	Y	To assess the value of the COPD assessment test (CAT) questionnaire for screening dairy farmers	Our predictive models can both benefit farmers by providing early diagnosis and management of their COPD and prevent unnecessary, costly spirometry during the screening process.
Kim et al. 2010 (61)	16 flavour manufacturing companies, 467 workers	Flavour manufacturing	Questionnaire (English and Spanish version of CDPH field-tested) Spirometry	Y	To describe surveillance programme for lung diseases based on cross-sectional questionnaire and respiratory data	Surveillance identified physician diagnosis of moderate to severe occupational lung disease that supported subsequent interventions
Kreiss et al. 2012 (58)	724 workers (585 [80.8%] males, 139 [19.25] females)	Diacetyl (2,3-butanedione) and artificial butter flavouring powders and vapours	Standardised questionnaire Spirometry	Y	To distil implications of a spirometry surveillance programme for future monitoring of effects for workers at risk of rapidly progressive occupational lung diseases	Spirometric surveillance of flavouring workers can identify individual workers with abnormal FEV_1 decline for preventive intervention

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Lewis and Fishwick 2013 (7) Review	n/a	ilica, agents causing COPD, agents causing asthma, agents causing other lung diseases	Respiratory questionnaire Lung function (absolute and percentage predicted FEV1 and FVC). Cross-sectional measures of FEV1 and FVC within shift changes, longitudinal changes, FEV1/FVC < 5th percentile (as a definition of COPD) and standardised residual of the FEV1 < 1 Radiological abnormality Immunology Bronchial hyper-responsiveness FeNO	Y	To identify areas of good practice with respiratory HS and to formulate recommendations for practice.	A standard validated questionnaire with associated guidance should be developed
Mehrparvar et al. 2012 (55)	588 subjects (297 individuals with normal spirometry and 291 with abnormal spirometry)	Not reported	Spirometry	Y	To compare various lung function metrics for the diagnosis of restrictive and obstructive spirometric patterns	FEV_6 and FEV_1/FEV_6 can be used as surrogate parameters for FVC and FEV_1/FVC as they showed acceptable sensitivity, specificity, positive predictive value, and negative predictive value in occupational health evaluations.

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Meijer et al. 2001 (59)	314 workers from 3 studies (144 workers in the concrete industry, 79 in the rubber industry, and 91 in the paper industry) used to develop a prediction algorithm and data from a fourth study used to evaluate it (n = 79 rubber workers).	Rubber, concrete and paper industries	Questionnaire (cough or phlegm production for 3 consecutive months during previous 2 years, wheeze for more than 1 week, or shortness of breath when walking with people of their own age on level ground (dyspnoea grade >=3) Spirometry Prediction model	Y	To justify group(s) of risk factors for occupational COPD by the optimal use of diagnostic tests and procedures commonly available in non-occupational health practice.	Before surveillance programmes for occupational COPD can be initiated in occupational health practice the benefits of such programmes should be weighed against the costs
Rose et al. 2012 (42)	US military personnel deployed to Iraq and Afghanistan	Burn pits operating in close proximity to where troops live and work, to industrial emissions, and to PM (particulate matter) from ambient desert dust	Questionnaire, Spirometry Physical readiness testing	N	To develop consensus recommendations for medical screening for lung diseases in veterans	There is a need for targeted, practical medical surveillance for lung diseases for all symptomatic deployed personnel

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
da Silva Filho et al. 2019 (62)	Unionised civil construction workers in Cuiaba (n = 545)	Dusts, chemicals, and other contaminants	Questionnaire Spirometry Chest radiography	N	To analyse the prevalence and symptoms predictive of future respiratory illness among construction workers occupationally exposed to environmental contaminants	Biological monitoring of civil construction workers might be useful to improve occupational HS outcomes within the primary care setting
Johnson et al. 2009 (17)	Famers aged 55 and over who engaged in farm work within the past year (n = 134)	Work as a farmer	Respiratory symptoms questionnaire. Spirometry	N	To assess whether screening spirometry combined with telephone symptom survey represents a continued healthy worker effect or symptom reporting error	Misclassification bias may affect studies of older farmers that rely on symptom self-report, inaccurate by intention, or misperception as a measure of exposure to respiratory hazards

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Liao et al. 2014 (63)	Nanomaterial-handling workers and non-exposed control workers were recruited from 14 nanomaterial manufacturing and/or application factories in Taiwan. Baseline n = 158 exposed workers and n = 104 non-exposed control workers. Six months later, n= 124 exposed workers and n = 77 control workers were re-monitored (follow-up rate of 201/262, 67.2%).	Nanomaterials	Lung inflammation markers Spirometry	N	To explore the health hazards among workers handling engineered nanomaterials	Pulmonary markers, cardiovascular markers and antioxidant enzymes were associated with handling nanomaterials at the 6-month follow-up assessment

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Saraei et al. 2018 (64)	200 participants (Exposed group: 110 workers from production department; unexposed group: 90 office workers)	Metal fumes, iron oxide, polycyclic aromatic hydrocarbons, gases, resins, isocyanates, and dusts such as crystalline silica, and solvents comprising silica, carbon, lead oxide, manganese, toluene, and benzene	American Thoracic Society (ATS) questionnaire Spirometry	N	To thoroughly examine the acute effects of ambient respiratory dust on the respiratory system	Implementing the health promotion programme, period medical surveillance, and efficient use of respiratory protective equipment could help protect foundry workers from respiratory impairment

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Witt et al. 2017 (25)	Firefighters with a minimum of 10 years' service (n = 160). 119 vocationally active, 41 retired. Control group (n = 80), 68 active and 12 retired professionals (their vocation was not associated with exposure to the risks specific to the study group of firefighters).	Toxic agents present at fires	Questionnaire of Respiratory Symptoms by the Medical Research Council (personally modified). Morphology of peripheral blood erythrocyte sedimentation rate (ESR) Chest X-Ray Arterial blood gas Lung function (FVC, FEV1, FEV1%, FVC, MVV, FEF, FMF)	N	To analyse the influence of harmful factors in the workplace of firefighters on the clinical and functional state of the respiratory system	To provide those presenting with flow abnormalities in the bronchi with frequent monitoring of their health status

3.3 Pneumoconiosis (excluding asbestosis)

There were 14 studies and reviews of health surveillance for pneumoconiosis (Table 4). The publication years for the studies ranged from 2007 to 2021. Two studies were cross-sectional, six evaluated HS programmes (one of which considered quality control of HS), four studies evaluated a specific HS programme, one was a longitudinal study, one was a case series, one included the development of a diagnostic model, and one determined the effectiveness of serum and urinary biomarkers as screening tools.

Six studies looked at silicosis in workers exposed to respirable crystalline silica (RCS). Another six looked at silicosis and coal-workers pneumoconiosis (CWP) in workers exposed either RCS and coal dust, or coal dust alone, and one looked at military personnel exposed to particulate matter from desert burn pits. One review did not specify a specific exposure.

Consensus on the use of questionnaires in the HS for pneumoconiosis was lacking. Several studies reported a lack of sensitivity and specificity for respiratory questionnaires in the diagnosis of early, or 'simple,' silicosis. A number of studies highlighted that workers with radiological evidence of silicosis reported no respiratory symptoms (65). However validated symptom questionnaires were useful in coal miners with progressive massive fibrosis and in military personnel (42).

Spirometry was frequently used in HS for pneumoconiosis, though evidence or its use was inconsistent. One study reported a lack of sensitivity and specificity for spirometry in HS for silicosis (66). One study reported carbon monoxide lung diffusion (DLco) was the most frequent lung abnormality in subjects with silicosis and was more sensitive and specific than spirometry, although commented on the lack of routine availability (65). Similarly, an Australian study of CWP found body plethysmography to be more useful than spirometry in diagnostic algorithms (66). Another study suggested lung function testing should be carried out annually and highlighted that in younger workers decline may be within normal ranges (a loss of 15% from a baseline value should be considered abnormal) (67). A dedicated programme (SPIROLA, freely available from NIOSH) was found to be useful in detecting accelerated lung function decline in CWP (68).

Several studies commented on radiological tests for pneumoconiosis, including plain chest radiograph (CXR), high resolution or low dose computed tomography (HRCT or LDCT). No studies reported specifically on the optimal interval from exposure, timing, and duration of imaging for different pneumoconiosis.

- for silicosis,
    - in workers exposed to artificial stone CXR lacked sensitivity, and half of workers with a final diagnosis of silicosis had a normal screening CXR (ILO grade 0) (69)

    - workers with relatively advanced silicosis may be missed by respiratory questionnaire, spirometry, and CXR screening alone and more sensitive measures of HS (HRCT) may be required (67)
    - HRCT was more sensitive than CXR in detecting small parenchymal changes, interstitial fibrosis, and pleural abnormalities in stonemasons (67)
    - in a study of pneumoconiosis among construction workers, HRCT was superior to chest X-ray in identifying early parenchymal lesions, although there was no information on whether this improved outcomes (70)
    - in artificial stone workers, HRCT was most sensitive for diagnosis (it was carried out in subjects with abnormal spirometry, DLco, or chest X-ray, the latter being performed every three years) (65)
    - one study of Italian workers exposed to RCS supported using NIOSH recommendations for spirometric and radiographic surveillance at 5-year intervals throughout their working career (71)
    - the optimal imaging technique for silicosis requires further evaluation (69, 71)
- for CWP in coal miners,
    - the total number of radiographs undertaken by miners correlated with earlier detection of pulmonary massive fibrosis (PMF). Miners with multiple CXRs tended to have increasing profusion of small opacities that were identified prior to identification of PMF. The study recommended a scheduled CXR at commencement of exposure at and least every three years thereafter (68)
    - the digitalisation and storing of CXRs should be centralised and available to different organisations or professions involved in the care of coal workers (68)
    - HRCT was more sensitive than CXR in detecting CWP but was frequently difficult due to cost (72)
    - there is a lack of an agreed classification system for more advanced CT scans (72)
    - HRCT was more sensitive than CXR for detecting parenchymal and pleural abnormalities and interstitial fibrosis in Australian coal workers, but was limited by equipment availability, costs, and radiation exposure (68)
    - pneumoconiosis can continue to progress after miners' work exposures cease, and so lifelong respiratory health surveillance may be justified (73)

Several other studies commented on other tests for HS in pneumoconiosis including exhaled breath and other biomarkers, exercise testing, and learning algorithms. They found:

- in a biomarker study of workers exposed to RCS at risk of silicosis, 4-hydroxynonenal (4-HNE) was the only one capable of distinguishing between high and low exposure to silica, but did not seem sufficiently sensitive to diagnose restrictive lung deficit (66)
- in military personnel at risk of silicosis a 1.5 to 3 mile run was an indirect measure of pulmonary capacity (42)

Table 4: Pneumoconiosis including Silicosis

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Corradi et al. 2019 (66)	Exposed group (62 workers): 58 men and four women. 14 with respiratory restriction and 48 without restrictions	Free crystalline silica	Body plethysmography Spirometry Exhaled breath condensate (EBC) biomarkers of oxidative stress (EBC 4-hydroxynonenal levels levels) Clinical anamnestic questionnaire (work-related respiratory symptoms and conditions including cough, wheezing, bronchial catarrh, physician-diagnosed restriction or obstruction, and allergic diseases [yes/no]).	Y	To investigate the validity of using spirometric parameters to formulate a suspicion of restrictive lung disease in clay excavation workers exposed to free crystalline silica (FCS) and compare the findings with body plethysmography data	Spirometry is not sufficiently sensitive to diagnose respiratory restriction in workers exposed to FCS (Free crystalline silica)
Guarnieri et al. 2020 (65)	Workers in the finishing department of ornamental stone companies with an occupational exposure to dust of quartz conglomerates (n = 45)	Quartz	Questionnaire Lung function tests ($VC/FEV_1/RV/TLC/DLco$) Chest X-ray Chest HRCT Biopsy	Y	To describe the incidence and clinical functional and radiological characteristics of silicosis in workers involved in fabrication of quartz conglomerate countertops	DLco should be added to spirometry for HS and HRCT is indicated for screening of workers with high cumulative exposure to silica

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Hall et al. 2020 (73)	Surface coal miners participating in the Coal Workers' Health Surveillance Programme (n = 6790)	Coal mine dust	Radiography	N	To describe the prevalence of pneumoconiosis in US coal miners	Lifelong respiratory HS for workers exposure to crystalline silica and/or clam mine dust has been recommended by WHO/ILO.
Hoy et al. 2021 (74)	826 workers registered with the programme: 587 workers completed primary evaluation; 239 workers completed secondary evaluation	Respirable crystalline silica from artificial stone benchtop	Standardised questionnaire Physical exam Chest X-ray Respiratory function testing with assessment of spirometry and gas transfer Non-contrast high resolution CT of the chest Panel of blood tests	N	Report of the 7 initial cases of silicosis associated with artificial stone	In the Australian context, significant more worked is need regarding HS to protect workers in this industry
Laney et al. 2017 (71)	192 miners	Coal mine dust	Radiographs	N	Examine the radiographic progress of opacities among coal miners with at least one radiographic classification of PMF	NIOSH recommends all miners participate in spirometric and radiographic surveillance at 5-year intervals throughout their career

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Nicol et al. 2015 (67)	Stonemasons (n = 6)	Silica	Symptom questionnaire Chest X-ray Chest HRCT	N	Experience with 6 cases of silicosis in young construction workers	Further consideration of the optimum means of HS for those at risk is required
NIOSH 2011 (75)	Miners	Coal dust and silica		N	Update of previously published review with response to US coalminers	Prevalence of CWP appeared to have stopped declining around 1995-1999, and has risen since then
Reilly et al. 2018 (76)	1,048 silicosis cases in the State of Michigan	Respirable crystalline silica	Medical questionnaire Medical records (pathology reports from lung biopsies, chest radiograph reports, high-resolution computed tomography reports, chest radiograph images, and pulmonary function tests) Spirometry	N	Update to the Michigan silicosis surveillance scheme	Cases of silicosis are underreported

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Rose et al. 2012 (42)	US military personnel deployed to Iraq and Afghanistan	Burn pits operating in close proximity to where troops live and work, to industrial emissions, and to PM (particulate matter) from ambient desert dust	Questionnaire Physical readiness testing			
Shriver et al. 2018 (72)		Coal dust, silica dust	Chest image Pulmonary function tests Arterial blood gas	N	To examine issues around diagnostic uncertainty and medical surveillance of CWP	Miners fear workplace discrimination for participating in black lung screening programmes
Suarthana et al. 2007 (70)	Dutch natural stone and construction workers aged 30+ (n = 1291)	Silica	Diagnostic model for ruling out pneumoconiosis	N	To develop simple diagnostic model to examine the probability of an individual worker having pneumoconiosis from questionnaire and respiratory results	The model is an efficient and effective instrument to rule out pneumoconiosis among construction workers

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Won et al. 2019 (77) Review			Chest radiography Spirometry	N	Review of special periodic health agencies in the Republic of Korea	Flexible responses are required for the development of new diagnostic methods and important if diagnostic criteria based on new theories
Wood & Yates 2020 (78) Review		Coal mine dusts and silica/ mineral dust	Occupational history and exposure assessment Respiratory symptom questionnaire Spirometry and full lung function testing Chest imaging (chest radiograph, HRCT)	Y	When is respiratory HS useful (for exposure to mineral dusts)	A programme relies on a combination of tests to provide indicators of possible disease
Zosky et al. 2019 (68) Review	Australian workers exposed to coal dust and at risk of developing coal workers' pneumoconiosis (CWP)	Coal dust	Mandatory screening X-ray screening using the ILO standard Questionnaire Spirometry	N	To understand the important potential determinants of CWP prevention	Recommend implementing a national screening programme for at-risk workers, with use of standardised questionnaires, imaging, and lung function testing

3.4 Chronic beryllium disease (CBD)

There were 3 studies and reviews of health surveillance for CBD, also known as berylliosis, in workers exposed to beryllium (Table 5). The publication years for the studies ranged from 1996 to 2013. One study was a cross-sectional epidemiological study, and the other two were evaluation of ongoing beryllium-related health surveillance programmes.

One study specifically discussed respiratory health questionnaires and reported them to be more useful in obtaining occupational histories of the workers, rather than for symptom ascertainment (79).

For pulmonary function testing, one study found they were not a reliable screening tool for chronic beryllium disease (CBD) (80), as observed defects could be obstructive, restrictive and mixed, and were not deemed specific for CBD (80). The same study explored the use of cardiopulmonary exercise testing (CPET) and found this was an earlier indication of CBD occurring before the onset of clinical symptoms (80).

For radiological tests, one study reported an absence of imaging findings in early CBD (80). The authors concluded that chest X-rays are insensitive and non-specific for the diagnosis of CBD (80).

The blood beryllium lymphocyte proliferation test (BeLPT) was reported as more sensitive and specific than other testing, particularly with serial measures, and has become standardised as the mechanism for screening and diagnosis of beryllium sensitivity and CBD (80). Sensitisation rates in exposed populations were reported in one study were around 2.5% (79). The same study highlighted that false positive BeLPTs occur and serial measures are needed, but only one case of CBD with CXR changes was found without BeLPT sensitisation. Another study demonstrated inter-laboratory differences in normal ranges in BeLPT, and there was a lack of evidence to support further investigations following a single abnormal BeLPT (80). Furthermore, there was no clear evidence to support timing and length of post-exposure screening with BeLPT and this should be explored further (80).

The other review of HS for beryllium suggested that beryllium sensitisation can occur following low exposure in susceptible individuals (81). It also suggested that occupational physicians in industries that use beryllium and/or beryllium alloys should strongly consider the potential for employees to develop beryllium sensitisation and CBD even though routine health monitoring is provided and that it is important to recognise that exposure to beryllium at levels below the occupational exposure limit might cause disease in some employees (81).

Table 5 – Beryllium-related conditions

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
MacMurdo et al. 2020 (80) Review	Workers exposed to beryllium	Beryllium	Blood beryllium lymphocyte proliferation test (BeLT) BAL cell BeLT Pulmonary function testing	Y	Review of screening of workers exposed to beryllium	With new requirements (in the US) for beryllium screening likely to see an increase in beryllium sensitivity and CBD
Stange et al. 1996 (81)	Current (n = 1885) and former (n = 2512) Rocky Flats employees	Beryllium	Lymphocyte proliferation test Beryllium Health Surveillance Programme (BHSP) questionnaire Chest X-ray	Y	Describes an ongoing programme to identify and assess beryllium sensitisation and CBD in a nuclear industry workforce	The lymphocyte proliferation test is used to identify sensitised individuals and chest X-rays CBD
Thomas et al. 2013 (79)	298 current and former workers	Beryllium	NIOSH cross-sectional survey Blood samples to test for BeLT Clinical evaluation (bronchoscopy with transbronchial biopsy and bronchoalveolar lavage (BAL), lymphocyte proliferation test on lavage fluid (BALLPT), and biopsies.	Y	Assess a HS programme in preventing beryllium sensitisation	Continuing refinements made to the preventive programme have provided additional protection again beryllium sensitisation

3.5 Asbestosis and Mesothelioma (including early markers of malignant transformation)

Seven studies examined health surveillance in asbestos-exposed populations, primarily looking for asbestosis and mesothelioma (including early markers of malignant transformation) (Table 6). The publication years for the studies ranged from 2015 to 2020 and most examined workers with historical exposure to asbestos. Four were cross-sectional studies and three studies evaluated health surveillance. None of the papers in this section mentioned use of questionnaires. Only one study focussing on biomarkers of asbestos exposures mentioned use of lung function testing (82).

Of the four papers that mentioned radiography, the Italian Consensus conference on asbestos suggested no mode of imaging has sufficient sensitivity and specificity for early diagnosis of malignant mesothelioma. However, the same study suggested that HRCT was the recommended imaging technique for asbestosis (83). One study supported the use of HRCT in high-risk workers exposed to asbestos-contaminated materials, although commented on its expense (84). The biomarker study suggested that chest X-ray and high-dose CT should be performed to evaluate the presence of asbestos-related disease, without specifying which diseases (82). A study of chest ultrasonography in HS of asbestos-related pleural disease suggested a potential role for ultrasound (supplementary to HRCT) in detecting early asbestos-related pleural abnormalities, with two-thirds of CT abnormalities found on ultrasound but 47 (from 117 workers) additional abnormalities found on ultrasound not seen on CT (85). The authors commented on the reduced cost and radiation associated with ultrasound, but that this test was limited to certain areas of the lung (ultrasound cannot image the apical subscapular or paravertebral area), was not widely available in health surveillance, and that further research was needed to clarify whether using ultrasound may enhance early recognition of pleural mesothelioma (85)

Several studies assessed the use of biomarkers to assist with early detection of asbestosis or mesothelioma. One study reported a combination of soluble mesothelin-related peptides (SMRP), fibulin-3, CEA and urinary 8oxodG can be used in health examinations to screen for pneumoconiosis in workers exposed to asbestos-contaminated materials (84). A strong increase in 8-oxodG was found in workers who have been employed for 10 or more years in asbestos plants (86). Increased immune mediator concentrations were observed in the sera of asbestos-exposed workers compared to controls for human fibroblast growth factor (FGF0b), vascular endothelial growth factor (VEGF), CCL5 (RANTES), CXCL10 (IP-10), CLEC11A (SCGF-b), CCL27 (CTACK), CCL11 (EOTAXIN), interleukin (IL)-5 and IL-6 (87). Other biomarkers identified included mesothelin and osteopontin (OPN), and some recently investigated molecules such as high mobility group box 1 (HMGB1) protein, fibulin-3, and some miRNAs (88). One study commented on the production of specific growth factors dually involved in early inflammatory response and pro-tumoral activity before clinical evidence of related disorders, suggesting that their over-expression may precede the onset of asbestos-related diseases, and that such biomarkers could be used

in health surveillance for workers with a history of asbestos exposure (87). However, several papers highlighted that biomarkers for early asbestos-related lung disease lack sensitivity and specificity and there was a lack of longitudinal studies evaluating their use in health surveillance programmes (82) (83) (88).

In summary, HRCT was reported to be sensitive and specific for diagnosing parenchymal changes seen in asbestosis in asbestos-exposed workers. For asbestos-related pleural disease, ultrasound may be a useful adjunct but lacked evidence to support its use in a HS setting where it requires specialist expertise and interpretation. There was little evidence to support the routine use of biomarkers in health surveillance for asbestos-related lung disease. No studies looked at outcomes in the long term or evaluated how the presence of current abnormalities impacted disease progression or prognosis.

Table 6: Asbestosis and Mesothelioma (including early markers of malignant transformation)

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Yang 2019 (84)	Stone workers in Hualien (n = 138) 48 with pneumoconiosis, control group of 90 without pneumoconiosis	Serpentine rock, nephrite, antigorite, or talc.	Questionnaire Chest X-ray Pulmonary function test FeNO test Tests for serum SMRP, fibulin-3, CEA and urinary 8-OHdG	N	To assess the diagnostic accuracy using the serum and urinary biomarkers for pneumoconiosis in workers exposed to asbestos-contaminated materials	Machine learning algorithms, including variables of sex, age, soluble mesothelin-related peptide, fibulin-3, carcinoembryonic antigen and 8-OHdG/creatinine, can predict pneumoconiosis with high accuracy in workers exposed to asbestos-containing materials.

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Cellai et al. 2020 (86)	Study volunteers were randomly selected among a group of asbestos workers, who were under a program of health surveillance at University Hospital of Pisa, Pisa, Tuscany Region, Italy. Asbestos workers (n = 98) which included former workers (n = 59) and current exposed workers (n = 39). Unexposed controls (n = 87)	Asbestos	None	Y	To develop biomarkers that can easily identify those subjects with past exposure to asbestos	8-oxodG can contribute to identifying people with increased genetic damage. Adduct measurement could be used in combination with other complementary biomarkers

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Comar et al. 2016 (87)	123 male workers with a history of definite exposure to amphibole asbestos (84 of which enrolled in a health surveillance programme, 46 of whom had pleural plaques, pleural thickening and/or pulmonary fibrosis)	Asbestos	Cytokines, chemokines, and growth factors (HGF, CTACK, SCGF-b, IL-6, EOTAXIN, IP-10, RANTES, REGF, IL-5, FGF-b, PDGF-b, TNF-α)	Y	To investigate immune mediators relevant to biochemical response to asbestos exposure	Findings raise intriguing questions on effective role of certain proteins as biomarkers of systemic inflammation associated with asbestos exposure, especially the chemokine RANTES

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Foddis et al. 2018 (88) Review	Asbestos exposed population	Asbestos	Single biomarkers for early diagnosis: 1) “soluble mesothelin-related peptides” (SMRP) 2) Osteopontin (OPN) 3) megakaryocyte potentiating factor (MPF) 4) Fibulin-3 5) High mobility group box 1 (HMGB1). Other possible biomarkers include BAP1 and microRNAs Multiple biomarker panels: combination of SMRP, plasma OPN, interluekin-6 (IL6), vimentin, desmin, hepatocyte growth factor (HGF).	Y	Review of research on biomarkers of prevention of asbestos-related diseases	Much of the biomarkers lack sensitivity and specificity. Recommend a need for more longitudinal research (rather than a single baseline assessment)
Magnani et al. 2015 (83) Review	Workers formerly exposed to asbestos or engaged in occupations with potential asbestos exposure	Asbestos	HRCT Additional health surveillance activity Pneumococcal and influenza vaccination and early treatment of respiratory infection	Y	Review of HS for asbestosis	No diagnostic test, including imaging and biochemical tests has sensitivity and specificity high enough to be adopted for early diagnosis of malignant mesothelioma. For asbestosis HRCT is the recommended imaging technique

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Paolucci et al. 2018 (82)	Male workers hospitalised in the University Hospital of Siena for suspected asbestos related diseases (n = 307)	Asbestos	Mineralogical analysis of BALF Chest X-ray HRCT Pulmonary function tests Serum SMRP	Y	To assess the reliability of BALF and SMRP as markers of previous exposure to asbestos	SMRP does not appear to be influenced by asbestos levels. Fibre concentration in BALF may be considered a reliable biomarkers of previous asbestos exposure.
Scarlata et al. 2017 (85)	117 subjects with documented exposure to chrysotile asbestos	Chrysotile asbestos	Pulmonary function tests (spirometry & DLco) CT scan Chest ultrasound	Y	To investigate thoracic ultrasound as an alternative to HRCTR for detecting early signs of malignant mesothelioma	Chest US detects two-thirds of pleural abnormalities seen on CT and picked up another pleural abnormality in 47/117 participants with no CT changes. The long-term impact of these findings was not examined. Chest US might complement HRCT in the HS of asbestos exposed populations. However, further research is needed
Sen 2015 (89)		Asbestos	Respiratory questionnaire Respiratory examination Spirometry Chest X-ray			

3.6 Lung Cancer

Five studies considered respiratory HS for lung cancer (Table 7). The publication years for the studies ranged from 2012 to 2020, and most considered workers with historical exposure to carcinogens. Three studies evaluated health surveillance, one was a cross-sectional study and one paper evaluated health surveillance programmes. Three studies looked at asbestos-exposed populations one examined coal/silica dust exposures, and one examined arsenic.

No studies examined the use of questionnaires in respiratory HS for lung cancer. The arsenic paper indirectly referred to respiratory symptoms, although it was not clear if this was from a medical examination or a questionnaire (90).

For physiology, the study of arsenic-exposed workers found that DLco was significantly lower in patients with pulmonary involvement in the HRCT examinations (90). In their review of respiratory effects of mineral dusts, Wood et al reported DLco was more sensitive and specific for diagnosing parenchymal lung abnormalities (for example emphysema and interstitial lung disease) than spirometry alone, although its use was limited by cost (78).

Several studies addressed the use of low-dose CT (LDCT) for HS for lung cancer in at-risk populations. One study reported LDCT surveillance was associated with a reduced risk of lung cancer mortality in asbestos-exposed workers (91). However, another stated that screening for lung cancer using LDCT was not proven to be efficacious (89). One paper highlighted the evolution of LDCT scanning and associated risk-reduction in radiation exposure, timings, and costs, and that LDCT is used in health surveillance for artificial stone workers in Australia. However, the same paper highlighted that LDCT is rarely available at worksites and is costly, so plain chest radiograph will likely remain the main radiological health surveillance test (78).

There was no clear evidence to support LDCT (or other CT modalities) in HS for workers at risk of lung cancer. However, CT was suggested to be more sensitive and specific than other imaging modalities for occupational lung diseases including pneumoconiosis and lung cancer. The evolution of LDCT in terms of cost-reduction, timing for tests, radiation reduction, and availability may lead to expansion of its use in HS programmes. In addition, including occupational exposures as well as smoking in identifying at-risk populations for LDCT screening of lung cancer is encouraged.

Table 7: Lung Cancer

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Barbone et al. 2018 (91)	Individuals enrolled in the Monfalcone Occupational Health surveillance programme, split into two sub-cohorts: 1. Men under surveillance at the Monfalcone Occupational health unit who entered the ATOM002 LDCT screening study Feb 2002 and Oct 2003 (n = 926). 2. Men enrolled in the same surveillance programme who did not enter the ATOM002 study (n = 1507)	Asbestos	LDCT	Y	To evaluate whether LDCT screening could reduce mortality from lung cancer in a high-risk population	Findings support the use of LDCT in surveillance programmes for asbestos-exposed workers
Ergun et al. 2017 (90)	Workers admitted to hospital with suspected occupational arsenic exposure (n = 256)	Arsenic	HRCT Pulmonary function tests Arterial blood gas Respiratory symptoms	N	To investigate the effects of occupational arsenic exposure on the lung by HRCT and pulmonary function tests	HS should be by diffusion test and HRCT

Study (Author, year)	Population studied	Exposure of interest	Intervention(s)	Research Question about HS?	HS Research Question	Most important respiratory HS related conclusion
Sen 2015 (89)		Asbestos	Respiratory questionnaire Respiratory examination Spirometry Chest X-ray			
Vehmas et al. 2012 (92)	Asbestos exposed construction workers originally screened for lung cancer with CT. n = 584 screened, of which, n = 185 deaths	Asbestos	Computed tomography (CT)	N	To work out the predictive value of pathological (HR) CT concerning long-term mortality among those screened for lung cancer	Pathological lung/pleural CT signs found in screening seem to predict deaths in the long-term, which may mean more medical surveillance of such individuals is required.
Wood et al. 2020 (78)		Coal mine dusts and silica/ mineral dust	Occupational history and exposure assessment Respiratory symptom questionnaire Spirometry and full lung function testing Chest imaging (chest radiograph, HRCT)			

4. Discussion

4.1 Summary of evidence

The review found no evidence to support changes to the currently adopted approach for respiratory HS in GB. The studies included were heterogenous in study question, design, and methodology, and reporting, and there was a lack of standardisation between studies.

Most studies included focussed early detection or diagnosis of asthma, obstructive airways disease, or pneumoconiosis, rather than investigating the effectiveness of the health surveillance programme. The majority were cross-sectional in design and there were no randomised studies. Few studies evaluated the impact of HS schemes in terms of longitudinal health benefits, secondary health effects to others surveyed, and costs.

There is a need to increase the knowledge base on the best approaches for HS considering:

- identifying and targeting populations at risk of WRRD
- how HS schemes should vary between different WRRD
- standardization of HS schemes across WRRD, workplaces, and industries where necessary/appropriate
- evaluating the sensitivity and specificity of novel techniques for HS, and the impact of their application in a real-world setting
- evaluating HS in terms of its health, economic and wider impacts (7)

This review considered six broad areas of WRRD where respiratory HS may be used.

Occupational asthma and occupational allergic diseases:

- most studies considered the use of respiratory symptom questionnaires, spirometry, or both. These techniques are relatively inexpensive and easy to perform in workplaces.
- individually, questionnaires and single measures of spirometry have low sensitivity and may underestimate the numbers of workers at risk of developing asthma.
- serial measures of spirometry improve diagnostic sensitivity for excess lung function decline and should be used to identify excess lung function decline and trigger specialist referral
- identifying specific groups of workers at risk of OA may be beneficial to target HS
- questionnaires should additionally screen for occupational rhinitis and eye disease
- most OA studies conducted HS within the first two years of exposure, although none compared this to alternative approaches. Disease onset in OA is most likely within the first two years. Frequency of respiratory HS should be at least annual in the years after first exposure, and more frequent HS may be appropriate within the first two years

- when available (e.g. for high molecular weight allergens and platinum salts), the use of skin prick test and/or specific serum IgE test can be useful for identifying sensitised workers at risk of OA. However, skin prick tests or IgE tests are not available for many low molecular weight allergens, and evidence to support HS using immunological testing is lacking
- fractional exhaled nitric oxide (FeNO) may be useful in earlier diagnosis of workers exposed to high molecular weight allergens and isocyanates, but its utility as a HS tool requires further exploration

Obstructive airways disease:

- questionnaires and spirometry are commonly used tools in monitoring obstructive airways disease including COPD
- longitudinal or serial evaluations of spirometry are needed to determine declines in lung function and need for further investigation
- using absolute cut-offs for spirometry (for example, forced expiratory volume in 1 second or forced vital capacity below 80% predicted) will fail to identify some workers with excess lung function decline. Longitudinal measures using standardised lower limit of normal reference ranges should be considered
- the development and use of diagnostic or predictive models, when properly validated, could be a useful tool in HS of obstructive airway disease

Pneumoconiosis (excluding asbestosis):

- questionnaires alone had low sensitivity and specificity for diagnosing pneumoconiosis but were useful in identifying cases in conjunction with other tools
- spirometry alone had low sensitivity and specificity for diagnosing pneumoconiosis but was useful in identifying cases in conjunction with other tools
- longitudinal or serial evaluation of spirometry should be undertaken to understand excess lung function decline. There are programmes available to monitor this (for example SPIROLA)
- for diagnosis of silicosis in secondary care, DLco and body plethysmography was more sensitive and specific than spirometry. However, the use of DLco as part of routine health surveillance is not established
- qorkers with radiological evidence of silicosis may be asymptomatic and have normal lung function. Therefore, radiological testing is essential in surveillance for silicosis.
- CXR was useful for diagnosis of silicosis but a proportion of workers with silicosis have normal CXR. No studies reported specifically on the optimal interval from exposure, timing, and duration of CXR for silicosis
- HRCT was regarded as the most sensitive tool for the detection of silicosis in secondary care. There were few studies evaluating the use of HRCT as a respiratory HS tool

- the current GB programme of CXR surveillance for silicosis is sensible, but this may need to be adapted in future to consider more sensitive radiological investigations in certain high risk groups

Chronic beryllium disease (CBD):

- BeLPT is standardized in screening and diagnosis of beryllium sensitivity (which can occur at very low exposures in susceptible individuals) and chronic beryllium disease (CBD)
- questionnaires on their own have low sensitivity and may underestimate the numbers of workers at risk of developing CBD
- spirometry alone has low sensitivity and specificity for CBD and the spirometric picture may vary between obstructive, restrictive, and mixed, making interpretation more difficult
- CXR alone is non-specific for the diagnosis of CBD, and there were very few individuals with CBD and CXR changes who were not also sensitised to beryllium.
- no studies commented on the schedule of HS for CBD

Asbestosis and mesothelioma (including early markers of malignant transformation):

- no studies evaluated the use of questionnaires
- HRCT was reported to be sensitive and specific for diagnosing parenchymal changes seen in asbestosis in asbestos-exposed workers
- for mesothelioma, ultrasound may be a useful adjunct to CT in diagnosis but lacked evidence to support its use in a HS setting where it requires specialist expertise and interpretation
- biomarkers may predict the onset of asbestos-related lung disease, but the tests lack sensitivity and specificity and have not been evaluated in HS programmes
- no studies looked at outcomes in the long term or evaluated how the presence of current abnormalities (for example early detection by ultrasound or biomarker) impacted disease progression or prognosis

Lung cancer:

- low dose CT (LDCT) is increasingly used in surveillance for lung cancer in general populations
- studies looked at LDCT in workers exposed to asbestos, arsenic and mineral dust (including coal and silica)
- no studies examined LDCT as a workplace HS tool and there was no clear evidence to support LDCT (or other CT modalities) in HS for workers at risk of lung cancer. CT is not widely available at worksites and studies considering the implications of CT in HS programmes in terms of cost, interpretation, and consequences (including radiation dose to intervals and finding of non-cancer abnormalities) were not explored
- CT was more sensitive and specific than other imaging modalities for lung cancer

- the evolution of LDCT in terms of cost-reduction, timing for tests, radiation reduction, and availability may lead to expansion of its use in HS programmes

4.2 Evidence gap this study was trying to fill

There are a number of reasons why HS of workers for occupational respiratory diseases is important. The most important of these is so that employers can detect respiratory health effects at an early stage and so ensure controls are sufficient to prevent further onset or progression of disease. HSE has provided advice on HS on its website, some of which is generic, covering all respiratory diseases and workplace sectors, and some of it is specific to individual sectors or substances in workplace.

This systematic review was carried out to understand what the current evidence base was for respiratory HS and whether HSE's advice for employers should be changed. In particular, the five following questions were posed with the aim to answer to the extent that the literature on this topic will allow.

4.3 Is there any evidence that the frequency of respiratory HS in HSE's guidance should be changed?

In general terms, the frequency of any HS should depend on the likely initiation and/or progression of the disease; if progression from exposure to disease can be very rapid then health surveillance will need to be more frequent compared to when disease progression is slow. Frequency will also depend on the circumstances and may need to be increased following identification of a problem in the workplace or following an emerging, sentinel situation (22).

There was no evidence that the frequency of respiratory HS in HSE's guidance should be changed. Evidence to support schedules of respiratory HS was lacking due to a lack of evidence on frequency of HS generally, evidence in specific WRRDs, and the overall quality of the evidence.

Frequency for respiratory HS varied depending on the WRRD of interest. Most studies of short-latency WRRD (e.g. rhinitis, asthma, hypersensitivity pneumonitis) tended to perform surveillance more frequently in the first two years, whereas surveillance for longer-latency conditions (e.g. silicosis, COPD) happened years from first exposure.

4.3.1 Occupational asthma and occupational allergic diseases

HSE have produced guidance for health surveillance for occupational asthma (93), which specifies that health surveillance should be carried out yearly (or as advised by the health professional). In case of spraying of isocyanates, health surveillance (spirometry and questionnaire) should be carried out on beginning of work, after 6 weeks, 6 months and then annually (94).

The latency period for occupational asthma is generally relatively short, with the highest incidence in the first few years of exposure (18). Thus, as the onset of occupational

asthma can develop very quickly following exposure, it is generally suggested that health surveillance should be more frequent following first exposure to potent allergens and asthmagens. Malo (2013) (95) suggested that frequency of health surveillance for high molecular weight asthmagens should be more frequent in the first 2 years following start of exposure. Similarly, Basketter et al. (29) describe a health surveillance standard in the enzymes detergent manufacturing sector, where following pre-employment tests, health surveillance is carried out every 6 months for the first 2 years. They also mentioned that the frequency could be increased if a new enzyme was introduced in the detergent produced. Jeebhay and Baatjies (19) also suggested a higher frequency for bakers during the first 2 years of exposure. In addition, they suggested an increased frequency for those with pre-existing asthma and/or rhinitis. Baur et al. (2012) (31) mentioned that because of the potentially short latency period for development for occupational asthma, surveillance programmes should start during vocational training for those at risk.

Fishwick and Forman (4) described a low- and high-level health surveillance for occupational asthma, where low level health surveillance is recommended where risk assessment is only suggestive of a respiratory hazard or when the likelihood of exposure is small. High level health surveillance is required when there is a known potent asthmagen in the workplace, where there is a known asthma problem including confirmed cases, or and/or where agents are labelled with an R1 notification (may cause sensitisation by inhalation and skin contact) (96). In addition to differences in the content of the health surveillance programme, the frequency of the respiratory symptoms questionnaire is also different between two levels of health surveillance. For the high-level surveillance, a questionnaire is issued at baseline, and at 6 and 12 weeks, followed annually thereafter, including annual testing of lung function. For the low-level surveillance programme, lung function tests and questionnaire are recommended at baseline with annual questionnaires thereafter (4). Fishwick and Forman further suggest that workers can be moved from low to high-level surveillance if they have pre-existing asthma or new onset of conjunctivitis, rhinitis, or respiratory symptoms (4).

Various other authors have described or suggested very similar frequencies for health surveillance for occupational asthma (13, 26, 28, 39, 43). Hence, generally a higher frequency is seen early earlier in employment or after start of exposure, followed by annual assessment (18). However, it is also recognised that it is often difficult to determine the optimum frequency of health surveillance programmes (28) and there is little empirical evidence for deciding on this.

In terms of HSE guidance, only for spraying of isocyanates is there an explicit mention of increased frequency of health surveillance (questionnaires only) (at start, after 6 weeks and after 12 weeks). There is no evidence of the benefit of increasing the frequency of health surveillance for workers exposed to respiratory allergens and asthmagens in terms of reduction of number of cases or severity of disease. However, there appears to be general agreement that health surveillance should be more frequent in the first 1 or 2 years for the important and potent substances.

4.3.2 Obstructive airway disease

For chronic obstructive pulmonary disease (COPD), HSE have produced guidance which states that respiratory health of workers (when exposed to relevant agents and health surveillance has been judged to be required) should be assessed before they start a job where exposure occurs, followed by regular testing '*…as advised by the health professional'* (97). This judgement of exposure to relevant agents is open to interpretation. Generally, COPD will develop slowly over years and the HSE guidance mentions that assessment of trends over time is more important than a single assessment. Longitudinal spirometry (in particular FEV_1) is useful in picking up decline in lung function in workers who are at risk of developing COPD due to workplace exposures (54). However, there does not appear to be any agreement on the frequency of spirometry to monitor COPD.

Other forms of obstructive lung disease may develop much quicker. For example, obliterative bronchiolitis results in obstruction of the smallest airways due to inflammation and symptoms can develop over weeks to months. This disease has been observed in workers who are exposed to diacetyl, used as a flavouring agent in the food industry (61). Because this disease can develop and progress quickly, any HS will need to be conducted relatively frequently (22). Kim et al. (61) and Kreiss et al. (58) describe a surveillance programme in the flavour manufacturing sector in California, using questionnaires and spirometry. Employees with potential exposure to flavouring ingredients were to be tested at start of employment and then every 6 months, until exiting the company. This is an example, where HS was implemented following an emerging or sentinel situation, which requires intensive investigations and HS. Following effective risk assessment and management, the frequency of the HS could be reduced.

4.3.3 Silicosis

Health effects from exposure to RCS (e.g. silicosis and lung cancer) usually have a long latency period. This is reflected in the supplementary HSE guidance for occupational health professionals for HS for workers exposure to RCS (98). This guidance recommends that HS for silicosis must be provided for workers who are involved in high-risk occupations, where workers are regularly exposed to RCS dust and there is a reasonable likelihood that silicosis may develop. Further examples of where HS for silicosis may be appropriate include previous cases of work-related ill health (WRIH) in the workplace, a reliance on RPE as an exposure control for RCS, or where there is evidence of WRIH in the industry. The guidance suggests a baseline assessment (questionnaire, lung function and possibly a CXR) before or shortly after first exposure to RCS. Subsequently, annual HS would include respiratory symptoms and lung function tests. After 15 years of exposure to RCS, a CXR should be included which should be repeated every 3 years.

The World Health Organisation (WHO) recommends that all workers exposed to RCS should undergo lifelong HS (67, 68). This would include a baseline CXR at start of employment, which should be repeated after 2 to 3 years, after which the frequency for

CXR can be reduced to every 2 to 5 years. Spirometry and symptoms questionnaires should be obtained annually.

In recent years, several publications have highlighted the risk of rapid development of silicosis in workers who are exposed to dust from cutting or finishing artificial stone (65, 69). Exposures to RCS in these workers can be very high, resulting in an increased risk of silicosis and a more rapidly progressive disease which affects people at a younger age. Rapidly progressive or accelerated silicosis will usually be accompanied by declines in lung function and respiratory symptoms.. For example, Nicol et al. (67) reported several cases of silicosis in stonemasons in the UK, with only mild symptoms and normal lung function. They highlighted the importance of a low threshold for early radiological examinations for workers in at risk occupational groups. However, exposure to levels of RCS above the workplace exposure limit represent a failure of exposure control, and HS is not a surrogate for this. HS measures may lack sensitivity or frequency to identify cases of accelerated or acute silicosis. This adequate exposure control is the first step in reducing risk of disease and is crucial for silicosis.

4.3.4 Asbestosis and Mesothelioma (including early markers of malignant transformation)

HSE Guidance (99) describes the requirements for HS in Great Britain for workers carrying out licensable work (such as asbestos stripping) and those carrying out notifiable non-licensed asbestos work (e.g. any refurbishment involving asbestos). For workers doing licensed work with asbestos, periodic medical surveillance must be conducted at intervals of 2 years or less (whilst exposure continues) with an initial medical examination '…*no more than 2 years before beginning exposure to asbestos'* (99). For non-licensed asbestos work, workers should have medical examinations at intervals no more than 3 years (whilst exposure continues) with an initial medical examination '…*no more than three years before beginning exposure to asbestos*' (100).

This review found no evidence regarding the frequency of HS for workers exposed to asbestos. Considering the latency period for asbestos-related disease, it would be appropriate to continue HS whilst exposure continues beyond the first 10 years of exposure. However, given the long latency of asbestos related diseases such as lung cancer and mesothelioma, it may be appropriate to continue HS after exposures have ceased, at least for workers with a long duration of or high cumulative asbestos exposure.

4.3.5 Pneumoconiosis

Occupational HS programmes have been described for several other health outcomes and/or exposures. For example, Laney et al. (71), Zosky et al. (68) have described HS programmes in coal miners to monitor for early signs of pneumoconiosis, but also other health outcomes (COPD, silicosis, etc.). In the US, NIOSH (75) recommends that all miners participate in HS (spirometry and chest radiographs) every five years throughout their working career. similarly, Wood et al. (78) describe a mandatory HS programme in

Queensland, Australia for coal miners, which should occur at start of employment and then every 5 years, whilst working with coal. Zosky et al. (68) recommend that digital radiography should be performed at start of coal dust exposure and then repeated at least every 3 years, depending on the results of ongoing assessments.

4.3.6 Other health outcomes

Stange et al. (81) and Thomas et al. (79) described HS programmes for workers exposed to beryllium. Stange et al. (81) describes the beryllium HS programme at Rocky Flats in the US. Individuals who were sensitised to beryllium were offered medical evaluations on an annual basis to monitor for the development of CBD. The authors highlighted that a number of workers were sensitised to beryllium but that the number with radiological abnormality in the absence of sensitisation was low. In addition, a 3-year retest frequency for other workers exposed to beryllium but who were not sensitised was implemented. More frequent retesting, for example annually, may be recommended, if prior clinical findings or recent symptoms suggest CBD. It was not clear from the paper how often workers were tested for beryllium sensitisation.

Thomas et al. (79) described a comprehensive HS programme by a manufacturer of beryllium in the US to prevent CBD. This included questionnaires and beryllium lymphocyte proliferation tests (BeLPT) to test for beryllium sensitisation. Single sample BeLPTs were conducted at hire (baseline) and at 6-, 24-, and 48-month intervals, followed by 5-year intervals.

4.4 Is there any evidence that the recommendation in HSE's guidance regarding the techniques (mostly using questionnaire and lung function) that should be used for respiratory HS should be changed?

There was no evidence that the techniques for respiratory HS recommended in HSE's guidance should be changed. Overall, respiratory questionnaires and lung function were the most common tools used for respiratory HS. Both tools alone were deemed to have low sensitivity and specificity and may underestimate the numbers of workers at risk of respiratory disease. For most WRRDs serial measures of spirometry, with validated 'cut-off' points for excess decline, are more useful than single measures in early diagnosis. Questionnaires and spirometry are affordable and deliverable in workplaces and are likely to continue to be an important part of HS in WRRD.

4.4.1 Occupational asthma and occupational allergic diseases

Several authors have commented on the use of questionnaires and spirometry in OA. For example, Mackie et al. (38) showed that out of 92 motor vehicle repair workers who were referred to their GP for further assessment (and possible onwards referral to a specialist in occupational lung disease), none was referred on the basis of abnormal spirometry alone.

Similar results were reported by Kraw and Tarlo (34), who found that no cases of occupational asthma were detected in workers exposed to isocyanates, by spirometry findings (without any reported respiratory symptoms). Cassidy et al. (23) reported most workers selected for further medical evaluation were identified through questionnaires, although some additional cases were identified through spirometry.

Respiratory symptoms may be underreported during HS. For example, Gordon et al. (13) showed that bakers working in UK supermarkets were less likely to report respiratory symptoms during occupational HS compared to an anonymous research study. In another study, bakers admitted that they falsified their responses because of fear for job loss following a diagnosis of OA. Similarly, Allan et al. (5) showed that the responses were more likely to be missing in the questionnaire used during occupational HS as compared to a cross-sectional study in animal laboratory workers, carried out by independent researchers.

These studies highlight that cases of OA may be missed on questionnaire and spirometry alone, and that abnormal spirometry may be found in some workers who underreport or underperceive symptoms. No studies included in the review compared HS approaches with or without questionnaires or spirometry. Both techniques will continue to be an important part of respiratory HS for OA due to their availability, ease of use, and interpretability in a workplace setting.

No standardised and validated questionnaires are available for occupational asthma and respiratory sensitisation (19). Several authors including Suojalehto et al. (45) and Szram and Cullinan (18) have highlighted the importance of including nasal symptoms and work-related rhinitis in HS. (We found no papers specifically considering health surveillance for rhinitis.)

Several authors have described diagnostic models for detection of sensitisation and/or workers at risk of occupational asthma. Most of these are based on self-reported symptoms and a medical history. Meijer et al. (6) developed a model for animal laboratory allergens. Similarly, Meijer et al. (2) developed a questionnaire-based model for prediction of work-related sensitisation in bakery workers, which identified 90% of bakers at risk of having asthma. Suarthana et al. (44) developed a model to detect wheat sensitisation which was based on respiratory symptoms and working in a traditional bakery. Jonaid et al. (101) described a diagnostic model to predict baker's asthma and rhinitis which was based on a self-administered questionnaire and a medical history taken by a physician. They argued that the probability of allergic asthma and rhinitis could be successfully estimated by this model, although they also acknowledge results will need to be replicated in other settings.

Szram and Cullinan (18) reported that lung testing undertaken in workplaces is often of low technical quality and prone to random error and that asymptomatic lung function abnormalities may sometimes be dismissed as technical issues. Still, they do not agree that spirometry is a worthless component of HS. Fishwick and Forman (4) argue that lung

function testing of workers has a role in HS as it is the main objective test available for widespread use.

Other tests have been described and suggested for HS for sensitisation and occupational asthma. These include fractional exhaled nitric oxide (FeNO) and immunological tests (IgE or skin prick tests). Coman and Lemiere (11) reviewed the use of FeNO in the screening and diagnosis of occupational asthma. They concluded that FeNO is a simple and non-invasive tool to measure airway inflammation and could be a potential tool for early detection of BHR. Bohadana et al. (15) showed that FeNO provided unique information over and above results from spirometry in a study of apprentice bakers and hairdressers. However, Coman and Lemiere (11) concluded that the use of FeNO yielded inconsistent results in different studies. This is likely because other factors will also contribute to the FeNO results, and these will need to be carefully considered when interpreting results. Further studies are needed to clarify its role in HS for occupational asthma.

HS programmes could usefully include skin prick tests or specific serum IgE measurements, if specific tests are available, validated and standardised for the relevant exposure (18, 20). Examples include tests for platinum salts and enzymes used in the detergents industry. Merget et al. (26) suggest that HS for workers exposed to platinum salts should include skin prick tests as the primary tool. The added advantage of these methods are that they can identify workers who are sensitised but asymptomatic. These workers may be at increased risk of developing occupational asthma and could be offered enhanced protection and HS (18). Baur et al. (31) suggest that a combination of different tests (questionnaires as well as physiological and immunological tests) can improve HS for occupational asthma. Although specific examples exist that demonstrate utility of immunological testing, particularly for high molecular weight agents, more evidence is needed before general recommendations of the use of these techniques can be made in the context of occupational HS (4).

The benefits of medical HS for work-related asthma were systematically reviewed in 2012 and the recommendations made by Wilken et al. (Figure 2) (20, 102)

TABLE 1 Recommendations

Recommendations	Strength of recommendation	Level of evidence
Questionnaire-based identification of all workers at risk of developing work-related asthma is recommended as basis for surveillance	Strong	High
Pre-placement screening for specific cross-reacting, work-associated sensitisation among potentially HMW allergen-exposed subjects is recommended in order to identify those at higher risk for work-related asthma	Strong	Moderate
Detection of sensitisation either by specific IgE or SPT should be included in surveillance (not only pre-placement) for identification of subjects at risk of work-related asthma with foreseeable regular exposure to HMW agents (such as laboratory animals, bakery dust, enzymes or latex)	Strong	Moderate
In atopics and subjects with pre-existing asthma or sensitisation, pre-employment investigation should be performed in order to inform them about their increased work-related asthma risk	Weak	Moderate
Because of the low PPV, exclusion of asymptomatic atopics or sensitised subjects from exposure to potential occupational allergens or irritant agents cannot be recommended		
In all workers with confirmed occupational rhinitis and/or NSBHR, medical surveillance programmes should be performed		
They should include periodic administration of a questionnaire, detection of sensitisation by standardised SPT or serum specific IgE antibodies, early referral of symptomatic and/or sensitised subjects for specialised medical assessment and assessment of asthma	Strong	Moderate
Surveillance programmes should already be implemented during vocational training of individuals at risk		
Identification of symptoms or sensitisation during surveillance should result in an investigation to confirm or exclude occupational asthma, work-related asthma, rhinitis and COPD	Strong	High
Risk stratification by diagnostic models can be used in medical surveillance to select exposed workers for further medical evaluation	Strong	Moderate
As a secondary prevention measure, a comprehensive medical surveillance programme should, in addition to early detection of sensitisation, allergic symptoms and occupational asthma, comprise exposure assessment and intervention targeted both at workers and exposure	Strong	Moderate

Figure 2: Recommendations for the conduct of workplace medical screening and HS from the European Respiratory Society taskforce on work-related asthma, 2012.

4.4.2 Obstructive airway disease

The use of spirometry within health surveillance for obstructive airways disease is generally accepted as an appropriate tool. Health surveillance specifically for COPD is not commonly performed. Most programmes are for OA or obliterative bronchiolitis, which may manifest with fixed airflow obstruction. Meijer et al. (59) suggested that classification of workers into risk groups, based on a number of symptoms (shortness of breath, wheezing, work-related lower respiratory symptoms) and being a heavy smoker, could be used to identify workers at increased risk for further investigation using spirometry, in order to save costs. Similarly, Jan et al. (56) developed a predictive model to screen for COPD in dairy farmers in France. They proposed that the use of the COPD Assessment Test (CAT) questionnaire in combination with the predictive model could avoid unnecessary and costly spirometry during the screening process, for dairy farmers who tend to be slow and/or reluctant to seek health care.

Others argue, however, that spirometry is the single most important as well as the simplest, cheapest, and non-invasive technique to detect preclinical cases of COPD (60).

Kreiss et al. (58) analysed spirometry data from workers exposed to diacetyl in California. The found that longitudinal spirometric surveillance of workers can be used to identify individual workers with an abnormal FEV_1 decline who have FEV_1 within the normal range. They concluded that good quality spirometry and longitudinal analyses of the spirometry data can reduce misclassification of work-related health effects.

4.4.3 Pneumoconiosis, lung cancer, and mesothelioma

In addition to respiratory symptoms questionnaire and lung function testing, chest X-rays have been used traditionally in HS for workers exposed to mineral dusts that can cause pneumoconiosis. The International Labor Organisation (ILO) have developed a classification scheme that should be used to describe and categorise radiographic abnormalities. Usually, chest radiographs are taken within a clinical setting, although mobile units are available. Although radiation dose is low, frequency of exposure should be kept to a minimum. Other imaging methods are increasingly available such as CT. Hoy et al. (74) argued that CXR was not as sensitive to identify workers with simple silicosis as HRCT. They quote a study by Newbigin et al. (103) who reviewed data from a health screening programme in Queensland, Australia, and found that 43% of workers with final diagnosis of silicosis had normal CXR. Savranlar et al. (104) compared CXR and HRCTs in early and low-grade coal workers' pneumoconiosis cases and found that discordance between the two methods was high, and suggested that HRCT should be used as a standard tool for detecting early pneumoconiosis. Guarnieri et al. (65) also found that in 24 cases of silicosis, HRCT identified abnormalities, whilst only 42% of CXR showed abnormal findings. They recommended that in addition to HRCT, DLco should also be added to spirometry for health surveillance of workers with high exposure to silica.

Recent outbreaks of coal miners' lung disease and silicosis in Australia led to the development of a position paper by the Thoracic Society of Australia and New Zealand who recommended enhanced surveillance methods to include CT scanning and testing of lung diffusion capacity (105). Wood et al. (78) suggested that HRCT scanning is becoming increasingly advocated as a first line tool for workers exposed to mineral dusts. However, this review found no studies that directly compared CT with plain radiography for the surveillance of pneumoconiosis. Technical developments in CT, including development of more widely available LDCT for lung cancer screening, understanding of the frequency of abnormal results, and applicability in workplace HS, may result in increased availability in HS settings and the effectiveness of these tools in the UK should be assessed.

4.5 Does either the frequency of or the technique used for respiratory HS vary depending on the disease being considered e.g. questionnaire and/or lung function for occupational asthma?

Questionnaires for respiratory health symptoms and spirometry are the two most used and accepted tools for HS, irrespective of the disease being considered. No standardised questionnaires for respiratory HS are available, and the content of the questionnaire will

need to be targeted to the exposure and health outcome. Questions asking whether symptoms improve away from work or on holiday, or whether they worsen at work, are important as markers of WRRD. Questionnaires including rhinitis or eye disease are also important to detect workers at risk of OA.

Single measures of lung function are not highly sensitive to respiratory disease, and longitudinal measures are important to detect changes in lung function and trigger specialist referral. Care must be taken in term of the quality of the spirometry and the emphasis should be on longitudinal interpretation of the lung function measurements. The development and use of diagnostic tools to assist in respiratory health surveillance should be explored, as this may also lead to standardisation of the data collection.

Additional tools are available that could be used to complement the use of questionnaires and lung function. For occupational asthma caused by allergens, the use of immunologic tools, such as serum IgE and skin prick tests, could be recommended for HS, if specific tests are available, in particular for workers with pre-existing asthma or rhinitis (19). For pneumoconiosis, radiological assessment with CXR or HRCT is recommended.

In terms of frequency, it is clear that for short latency diseases, such as occupational asthma, the interval between health screenings should be shorter at the start of exposure and may need to start during vocational training. In contrast, for long latency diseases there may be no need for an intensive HS programme at the start of employment as it is unlikely to detect any signs of disease.

It should also be considered that respiratory HS may need to consider different health outcomes as workers may be exposed to multiple hazards and/or the same exposure can lead to different respiratory health effects. For example, workers in the construction industry may be exposed to other hazardous agents (e.g. wood dust, paints, etc.) in addition to RCS that may be associated with COPD and occupational asthma. Magnani et al. (83) argued in relation to asbestos exposure and risk for of mesothelioma that HS should have a broad perspective considering different diseases associated with asbestos exposure and of the joint effect of asbestos and tobacco smoking on lung cancer.

4.6 Should the type of HS vary by the hazard e.g. flour vs isocyanates?

No studies included in the current review considered whether respiratory HS should vary by hazard, and instead focussed on different health outcomes (e.g. OA or silicosis). However, there was significant overlap between HS tools used for the spectrum of WRRD considered.

Questionnaires and spirometry are important for HS for many WRRDs. The type of hazard may influence HS tools available, for example some specific immunological tests are available for certain exposures, for example platinum salts, wheat, or beryllium. However, no effective immunological essays are available for most low molecular weight allergens, such as isocyanates, that can be used in workplace HS for OA (27).

Changes to HS programmes may be required in groups where there has been a change in hazard, for example in artificial stone workers at risk of accelerated silicosis. However, changes to HS are not a substitute for appropriate exposure controls, which should form the basis for protecting all workers.

4.7 What are the knowledge gaps or conflicting evidence in relation to HS to inform the future needs of HSE's health strategy to prevent work-related lung disease?

It is clear from this review of the literature that in general there is very little empirical evidence regarding the effectiveness of HS and the different tools available (14, 19, 89).

There are several areas that would benefit of further research:

1) identifying workers at risk of particular WRRD, and consideration of tailored respiratory HS for these individuals
2) derivation and validation of a standardised respiratory health questionnaire for use in WRRD
3) improving the reliability of questionnaires and spirometry in the surveillance of WRRD, including trigger points for action on lung function decline. This includes determining the best action following identification of a trigger point, including best destination for onwards referrals, who makes referrals, and the role of different healthcare providers (primary care, secondary care, and occupational health) in this process
4) the use of immunological testing for surveillance of WRRD, including understanding relationships between sensitisation and development of disease or where mechanisms of sensitisation are unclear
5) understanding the use of other biomarkers (fractional exhaled nitric oxide, exhaled breath, urine, blood, pleural fluid) as tools to monitor harmful exposures and in WRRD surveillance
6) the use of CT and other radiological tests in the surveillance of WRRD (particularly in early detection for pneumoconiosis and lung cancer)

Future research programmes should also continue to raise awareness of the risks of WRRD among employers, employees, healthcare professionals, and the general public.

4.8 What are the knowledge gaps or conflicting evidence in relation to HS to inform the future needs of HSE's health strategy to prevent work-related lung disease?

Although a substantial number of publications were identified from the literature search and screened, only 86 papers were included, a large proportion of which were either reviews of HS in general, or reviews of specific HS programmes. For those many of those studies providing primary evidence for HS, HS was often not the primary aim of the study. Thus, the volume of evidence in the scientific literature on the topic of respiratory (workplace) health surveillance for respiratory diseases was relatively small.

Some potentially relevant literature may have been missed during searching, particularly since many informative studies were related to HS rather than primarily about HS. This was exemplified in the difficulty of identifying additional studies from the bibliographies of the studies found. Indeed, when writing the discussion for this project, some additional references came to light and so were included in this section.

The heterogeneous nature of the studies identified and the large proportion of the primary studies not necessarily focussed primarily on respiratory HS made assessments of quality challenging. The overall impression is that the evidence considered was heterogenous and the quality of studies varied. In particular, no randomised controlled studies evaluated the long-term effects of HS. More resources should be invested in evaluating HS holistically, including in assessing and improving the sensitivity and specificity of the different tools, the consideration of secondary gains and losses, and the wider impacts on health (for example in raising awareness of health problems and health promotion). Impact assessments for HS are also important in evaluating the cost and benefit associated with different HS approaches. Tailoring evidence-based specific guidance for particular industrial sectors or occupation would seem appropriate use of resources.

5. Conclusions and Recommendations

The review found no evidence to support changes in respiratory HS. The studies included were heterogenous in study question, design, and methodology, and reporting, and there was a lack of standardisation between studies.

Most studies included focussed early detection or diagnosis of asthma, obstructive airways disease, or pneumoconiosis. The majority were cross-sectional in design and no randomised studies were identified. Most studies looked at the contribution of HS to earlier diagnosis. Secondary health effects, effects on other exposed workers, barriers to implementation, and costs were not commonly explored.

There was no evidence to support changes in the frequency of or tools used for respiratory HS. Further research is needed to evaluate the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness.

Occupational asthma (OA) and accelerated silicosis were identified as conditions of particular concern given their impact on working populations and potential for significant harm. Employers should be aware of the risk of these conditions and their legal obligations to protect workers, particularly in implementation of respiratory HS and prompt action on its findings.

Most studies in OA conducted respiratory HS more frequently in the first two years of exposure, where the risk of developing the condition is highest. Frequency of HS after this lacks evidence and requires further study.

Techniques for respiratory HS varied between studies. Respiratory health questionnaires and spirometry were the most used tools and are low cost and deliverable in workplaces. The sensitivity and specificity of both approaches vary according to the condition being surveyed, the subject, equipment available, and operator performance. These factors should be considered when interpreting results and early referral to specialists in occupational lung disease encouraged if there is a suspicion of WRRD.

There was no specific evidence to support a change in immunological testing in respiratory HS. The use of skin prick testing and/or specific immunoglobulin E (IgE) is useful for determining sensitisation to high molecular weight allergens such as laboratory animals, wheat, and flour enzymes, and also to platinum salts.

There was no evidence to support a change in radiological testing in respiratory HS. Further evidence is needed to support the use of high-resolution and/or low-dose computed tomography (CT) scanning as an alternative or adjunct to chest radiography for silicosis, other pneumoconiosis, and lung cancer.

There was insufficient evidence to suggest that the types of health surveillance, for a given health outcome, should vary substantially by the type of hazard. However, it is expected that HS frequency and tools will vary depending on the WRRD under surveillance, and

workplaces may utilise multiple HS tools or programmes where workers are at risk of more than one WRRD.

There are significant knowledge gaps in respiratory HS, and future research strategies should focus on:

- identifying workers at risk of particular WRRD and consideration of tailored respiratory HS for these individuals
- improving the reliability of questionnaires and spirometry in the surveillance of WRRD, including trigger points for action on lung function decline
- understanding the use of other biomarkers (fractional exhaled nitric oxide, exhaled breath, urine, blood, pleural fluid) as tools to monitor harmful exposures and in WRRD surveillance
- the use of CT and other radiological tests in the surveillance of WRRD (particularly in early detection for accelerated silicosis and lung cancer)
- the use of immunological testing for surveillance of WRRD, including understanding relationships between sensitisation and development of disease or where mechanisms of sensitisation are unclear

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Appendix 1 – Full search strategy for electronic databases

The following searches were conducted in Web of Science and a combined Embase and Medline search in the OVID platform:

Web of Science (search carried out on 20th January 2021)

1. TS=(occupation* or work* or employ*)

2. TS=(pulmonary or chest or lung or respiratory or pleura*)

3. TS=((health or medical or respiratory) NEAR/3 (survey* or surveillance or monitor* or question* or assessment* or test* or screen*))

4. 1 AND 2 AND 3

5. 1, 2 AND 3 – Limited to English Language and 2012-2021.

Results: 2,755

Removed 6 duplicates by date and title

Results: 2749 articles

OVID (search carried out on 20th January 2021)

MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions(R) 1946 to January 19, 2021 and Embase 1974 to 2021 January 19

1. occupation* or work* or employ*

2. pulmonary or chest or lung or respiratory or pleura*

3. (health or medical or respiratory) adj3 (survey* or surveillance or monitor* or question* or assessment* or test* or screen*)

4. 1 AND 2 AND 3

5. Limited 4 to English Language

6. Limited 5 to 2012-current.

Results: 8,700

Removed 2006 duplicates

Results 6694

The two searches were combined in Endnote to give 9443 results, and a further 1712 duplicates were removed to give 7731 results. All 7731 articles were uploaded to Covidence, and 29 duplicates were removed. The final number of articles to screen for title and abstract was 7702.

Appendix 2 – PRISMA Checklist

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	No, but an explicit statement was made as to why a quality assessment (and therefore risk of bias assessment) was not carried out.
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency, and imprecision).	The shortcomings in the evidence were described, but a formal risk of bias assessment was not undertaken because of the generally low quality (in terms of HS) of the included evidence.
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes

Registration	12	Provide the register name and registration number.	Yes

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title page
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	The Executive Summary doesn't strictly follow the structure specified in the PRISMA guidelines, but that it includes all relevant elements.
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	p11-12
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	P12
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	P14, the grouping of studies is by disease outcome as set out in the subtitles of the results section
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	P87
Search strategy	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	P87
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	P15
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	p15-16
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all	p15-16

Section and Topic	Item #	Checklist item	Location where item is reported
		measures, time points, analyses), and if not, the methods used to decide which results to collect.	
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	p15-16.
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Not applicable.
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	We recorded the most important HS-related conclusion in each results table.
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Study had to mention health surveillance, either explicitly or implicitly. We separately identified those studies that specifically had a research question about HS.
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	The studies were synthesised separately by respiratory health outcome. As mentioned above, missing data meant a blank space in the relevant place in the respective table.
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Simple tabulations by respiratory health outcome.
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	p16
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	This was not formally done (as it was not possible).
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	The only sensitivity analysis relates to whether or not the study had a specific research question concerning HS
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Not applicable.

Section and Topic	Item #	Checklist item	Location where item is reported
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not applicable.
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	p16
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	p16
Study characteristics	17	Cite each included study and present its characteristics.	p17 and Tables 2-7
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Not applicable
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Not applicable as qualitative synthesis carried out using SWiM guideliines
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Characteristics summarised in Tables 2-7, but risk of bias assessment not undertaken.
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Not appliable.
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Not applicable.
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable.
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not applicable.
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not applicable.
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	p63-78
	23b	Discuss any limitations of the evidence included in the review.	P77

Section and Topic	Item #	Checklist item	Location where item is reported
	23c	Discuss any limitations of the review processes used.	P77
	23d	Discuss implications of the results for practice, policy, and future research.	p63-78
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	PROSPERO (CRD42021225759)
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021225759.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	None.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	p2
Competing interests	26	Declare any competing interests of review authors.	p2
Availability of data, code, and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	None.

Early identification of work-related respiratory disease (WRRD) is associated with improved health outcomes and benefits for other workers. Respiratory health surveillance (HS) is a scheme of repeated health checks used for the early identification WRRD. Health and Safety law in Great Britain requires employers to implement HS when workers remain exposed to health risks even after exposure mitigation measures have been put in place.

The evidence-base that underpins respiratory HS has not been reviewed systematically since 2012. This research was commissioned to systematically review and consider any evidence that relates to respiratory HS to ensure that HSE's guidance on HS remains relevant and appropriate.

The review found no evidence to support changes in HSE's guidance on respiratory HS, equally no evidence was found to support changes in the frequency of or tools used for respiratory HS. Evidence gaps were identified for the efficacy of respiratory HS, its optimal frequency, variation by disease and exposure, new tools for respiratory HS, economic impact, and other aspects that may improve its effectiveness.

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