

IN-DEPTH REVIEW

Health surveillance for occupational respiratory disease

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Background	Occupational lung diseases remain common, and health surveillance is one approach used to assist identification of early cases.
Aims	To identify areas of good practice within respiratory health surveillance and to formulate recommendations for practice.
Methods	Published literature was searched since 1990 using a semi-systematic methodology.
Results	A total of 561 documents were identified on Medline and Embase combined. Other search engines did not identify relevant documents that had not already been identified by these two main searches. Seventy-nine of these were assessed further and 36 documents were included for the full analysis.
Conclusions	Respiratory health surveillance remains a disparate process, even within disease type. A standard validated questionnaire and associated guidance should be developed. Lung function testing was common and generally supported by the evidence. Cross-sectional interpretation of lung function in younger workers needs careful assessment in order to best identify early cases of disease. More informed interpretation of the forced expiratory volume in 1 s/forced vital capacity ratio, for example by using a lower limit of normal for each worker, and of longitudinal lung function information is advised. Immunological tests appear useful in small groups of workers exposed to common occupational allergens. Education, training and improved occupational health policies are likely to improve uptake of health surveillance, to ensure that those who fail health surveillance at any point are handled appropriately.
Key words	Lung function; monitoring; respiratory health; respiratory symptoms; surveillance.

Introduction

The World Health Organization states that occupational health surveillance ‘... is the on-going systematic collection, analysis, interpretation, and dissemination of data for the purpose of prevention, improving the health, work ability and well-being of the labour force’ [1], while the Health & Safety Executive (HSE) of the UK describes health surveillance as ‘putting in place systematic, regular and appropriate procedures to detect early signs of work-related ill-health among employees exposed to certain health risks; and acting on the results’ [2]. Health surveillance provides an opportunity to reinforce training and education of employees. Through the detection of ill-health effects at an early stage employers can introduce or improve controls to prevent progression of

ill-health. It also provides information to help employers evaluate health risks, for example by highlighting lapses in workplace control measures.

Irrespective of its definition, its intentions are self-evident; the general aims of health surveillance include detection of early disease, enabling either the removal of the affected worker(s) from the causal exposure, or indeed the removal or control of the causal exposure itself, or a combination of these approaches, improved quantification of health risk for a known exposure, the identification of (new) at-risk groups and the gathering of epidemiological data on occupational disease.

In addition to personal health impacts, occupational respiratory diseases place a significant economic burden on the individual, the state and the employer. For example, in 1995, the total cost in disability benefits

received by 205 sufferers of occupational asthma (OA) carried through to retirement age amounted to ~£1.8 million [3]. A more recent review placed the estimated cost of OA to society at £70–100 million (lifetime costs of all estimated cases of OA in 2003) with 49% of this borne by the individual and 48% by the state, with employers shouldering 3% [4].

The HSE has estimated the potential financial benefit from preventing all new cases of OA over a 10 year period, beginning in 2001, to be between £579 million and £1.2 billion [5]. Given that costs associated with a diagnosis of asthma are known to increase with disease severity [6–8], there are consequently potentially large economic savings to be made by better diagnosis and treatment of OA and limited but compelling data to link health surveillance programmes to cost effective reductions in OA [9,10].

Data for other occupational respiratory diseases are even less detailed. For example, there are little data available on the economic costs of occupational chronic obstructive pulmonary disease (COPD), although estimates put the total costs per patient of COPD (including direct and indirect costs) at £163 908 and the direct costs to the NHS at ~\$1.4 billion [11].

It is a legal requirement to provide health surveillance in a number of circumstances, the responsibility for this being with the employer [12]. An example would be health surveillance for silica-exposed workers when there is a reasonable risk of silicosis developing. More generally, it is the responsibility of all employers and employees to help prevent harmful exposures in the workplace [13].

Given these requirements, and increasing evidence relating to the causes and costs of occupational respiratory diseases, it is notable that there is no universally agreed approach to respiratory health surveillance.

We therefore report the findings of a literature review undertaken to identify any areas of common good practice within respiratory health surveillance in order to formulate some recommendations.

Methods

This literature review was carried out using Medline, Embase, Web of Science, NIOSHTIC, HSELINE, OSHLINE, RILOSH and CISDOC. The final review included only original research documents published in a peer-reviewed journal, excluding regulatory documents and reviews. The search, using predefined terms shown in Table 1, was limited to articles and documents published in the English language from 1990 onwards.

An initial sift of full titles or abstracts identified was carried out. Full documents were reviewed if the initial review deemed them likely to be relevant to occupational respiratory health surveillance. The following general inclusion criteria were applied: (i) only documents

pertaining to occupational respiratory health surveillance were included and (ii) articles primarily seeking to establish new causal links or collect epidemiological data were excluded.

As this process did not adhere strictly to a more typical systematic review, it was not felt appropriate to use an evidence quality grading system, such as those provided by SIGN. However, a data-extraction tool was devised for internal use and used to summarize relevant evidence. Resulting papers were grouped into comparable sections based broadly on industry sector, exposure type and disease process for data synthesis.

Results

Five hundred and sixty-one documents were identified on Medline and Embase combined. Other search engines did not identify relevant documents that had not already been identified by these two main searches. Seventy-nine of these were assessed further and 36 documents were included for the full analysis; Table 2 gives the details of these. For the purposes of specific reporting of findings, these have been divided into the following sub-sections for further analysis, with some overlap: (i) silica exposure (five articles); (ii) obstructive lung diseases, excluding asthma (4 articles); (iii) asthma (26 articles); (iv) other lung diseases (2 articles); and (v) mathematical modelling approaches.

(i) Silica exposure

Five articles dealing with industries traditionally associated with silica exposure and silicosis were identified, encompassing concrete [14], construction [15], ceramic [16], china clay [17] and brick manufacturing workers [18].

Questionnaire and occupational history

All but one of the identified studies used a respiratory questionnaire, modified from the British Medical Research Council Respiratory Questionnaire (BMRCRQ) [19]. Modifications had also been made to enquire about work-related respiratory symptoms. Suarathana *et al.* also included an additional question on the participants' general health ('How would you assess your recent health condition?' with possible answers being 'healthy' or 'unhealthy') [15].

Table 1. Search strategy used

1	Occupation* or work* or job* or staff* or employ*
2	Pulmonary disease* or chest disease* or lung disease* or respirator* disease*
3	Health surveillance or health monitor*
4	1990–2012
5	English language
6	1&2&3&4&5

Table 2. Details of 36 papers included in the review

First author, date of publication, reference number	Brief publication details
Silica category	
Meijer, 2001 [14]	Respiratory effects of exposure to low levels of concrete dust containing crystalline silica. One hundred and forty-four concrete workers were included. Questionnaire and spirometry available. Respirable concrete dust levels of $<1 \text{ mg/m}^3$ were associated with the presence of reduced FEV_1/FVC ratios, using the 5th percentile of that ratio. This dust had a respirable silica content of 10%.
Suarthana, 2007 [15]	A simple diagnostic model for ruling out pneumoconiosis among construction workers. Dutch natural stone and construction workers (1291). Questionnaire, spirometry, CXR available. CXR model using age, smoking history, job title, and duration of employment; self-rated health and FEV_1 could identify workers for CXR surveillance aiming to detect ILO 1/1. ILO $\geq 1/0$ seen in 10.1%; 1/1 seen in 2.9%.
Forastiere, 2002 [16]	Silicosis and lung function decrements among female ceramic workers. Six hundred and forty-two with CXR. Three hundred and eighty with spirometry. Smoking data and occupational history available. Duration of employment and age associated with lung function decline. 9/642 CXR with ILO $\geq 1/0$ (six with ILO $f 1/1$).
Rundle, 1993 [17]	Analyses of a 1990 chest health survey of china clay workers. Four thousand and ninety-six workers (including non-exposed). Respiratory symptoms, smoking data, employment history, spirometry available. CXR LO 1/0 associated with longer exposure, employment pre-1971. Smoking and low FEV_1 associated with respiratory symptoms. CXR abnormality associated with lung function decline. Greater than 6% of 'non-exposed' had ILO $\geq 1/0$.
Zuskin, 1998 [18]	Respiratory findings in workers exposed in the brick manufacturing industry. Two hundred and thirty-three workers, 149 controls. Occupational records, smoking data, respiratory symptoms, work-related questions, CXR and spirometry available. Symptoms related to exposure (and duration), smoking and age. Lower FEV_1 and FVC in exposed workers with effects also for age. No cases of pneumoconiosis seen.
Occupational airways (excluding asthma)	
Meijer, 2001 [14]	Respiratory effects of exposure to low levels of concrete dust containing crystalline silica. One hundred and forty-four concrete workers were included. Questionnaire and spirometry available. Respirable concrete dust levels of $<1 \text{ mg/m}^3$ were associated with the presence of reduced FEV_1/FVC ratios, using the 5th percentile of that ratio.
Meijer, 2001 JOEM [21]	Developed risk model to identify cases of COPD, included SOB, wheeze, WRLRS and smoking. With ≥ 1 of the above, 17/24 COPD cases identified in the validation group (as per the definition $\text{COPD} = \text{FEV}_1/\text{FVC} < 5\text{th percentile}$).
Meijer, 1998 [22]	Exposure-response study in rubber workers. Seventy rubber workers, 69 reference workers. Symptoms similar in two groups, FEV_1/FVC slightly lower in rubber workers and no significant smoking effect seen.
Kim, 2010 [23]	Industry-wide medical surveillance of US flavour manufacturing. Sixteen companies involved including 467 workers. Questionnaire, spirometry (including reversibility) quantity of diacetyl handled annually by each company available. Respiratory symptoms similar to that expected in general population, with over-representation of severe obstruction and obstructive lung disease in younger workers. OR of 4.5 for OB if working in firm handling $>800 \text{ lbs}$ of diacetyl annually.
Asthma	
Meijer, 2004 [24]	A strategy for health surveillance in laboratory animal workers exposed to high molecular weight allergens. Three hundred and fifty-one exposed workers. Questionnaire, spirometry, immunology (skin prick testing, IgE—to both total and common allergens) available. Gender, wheeze, allergic symptoms at work and $>20 \text{ h}$ exposure per week, elevated IgE (total and to common allergens) and positive SPT to non-lab animal allergens all associated with sensitization. Subsequent model developed to predict sensitization risk.

Table 2. (Continued)

First author, date of publication, reference number	Brief publication details
Cullinan, 1994 [25]	Work-related symptoms, sensitization and exposure in workers not previously exposed to laboratory rats. Two hundred and thirty-eight new workers. Thirty-one per cent reported ≥ 1 work-related symptom, and high exposure associated with positive SPT. No consistent relationship between exposure intensity and symptoms seen.
Allan, 2010 [26]	Assessment of respiratory health surveillance for laboratory animal workers. Questionnaire versus pre-existing occupational health questionnaire assessed. Three cases of OA detected, spirometry alone detected no cases of OA although limited data supplied.
Brant, 2005 [27]	Comparison of existing health surveillance scheme with a cross-sectional study. Questionnaire and IgE available. Industry approach 22% reported symptoms, compared with 64% in cross-sectional group from the research study. High drop out rate in industry approach, possibly due to staged nature of surveillance and need to visit GP for blood tests, both avoided in cross-sectional research study.
Mackie, 2008 [28]	Effective health surveillance for OA in motor vehicle repair assessed with questionnaire and spirometry. Generally spirometry thought to be less helpful, but highly selected population identified for further study, and no information given about more minor lung function abnormalities dealt with at paper case review stage.
Merget, 2001 [29]	Effectiveness of medical surveillance programme for the prevention of OA caused by platinum salts: a nested case-control study of 299 participants and 66 controls. Questionnaire, SPT, spirometry, IgE and histamine challenge available. Fourteen SPT positive converters were identified, with a mean time to conversion of 30 months. SPT became negative again after removal from exposure.
Kraw, 1999 [32]	Study to assesses causes of medical surveillance changes leading to specialist referral from an isocyanate-using workplace. Thirty-nine workers referred. The questionnaire had detected five workers with non-OA, two with possible OA and one with OA.
Murphy, 2002 [33]	Implementation of statutory occupational respiratory health surveillance. One hundred and sixty-eight NHS and 177 industry workers. Reviewed available OH records, and industry workers more likely to be evaluated by occupational physician. Health surveillance variable; surveillance more likely to be carried out in industry.
Labreque, 2011 [34]	Medical surveillance programme for diisocyanate exposed workers. Motor vehicle repair and body work industry, with a 90% response rate from 2897 workers and 66 controls. Comparison made between health surveillance programme and a pre-introduction population. After two years health surveillance, the population had improved methacholine challenge results. The authors concluded that health surveillance detected cases of OA at a less severe stage.
Johnston, 2009 [35]	Occupational surveillance of older farmers, including 134 farmers greater than 55 years of age. Wheeze (OR 11.4) and SOB when hurrying (OR 11.6) were associated with self-reported asthma. Twenty per cent of farmers had an $FEV_1 < 80\%$ predicted, suggesting the under-reporting of symptoms.
Ott, 35 [36]	Respiratory health surveillance in an isocyanate (toluene diisocyanate) production unit, 1967–97: clinical and lung function analyses of 313 workers, with 158 controls. A physician diagnosis of OA was used. Within the OA group—increased risk of wheeze, chest pain on exertion, and ≥ 1 symptom. In the exposed group overall there was no increased risk of symptoms. Within OA group there was evidence of decreased lung function but no significant difference between exposed and referents.
Senthilselvan, 1996 [37]	Grain workers (1211). Greatest decline in lung function seen in (ex) smokers, and persistent wheeze also associated with lung function decline.
Bernstein, 1993 [38]	Cross-sectional study of 243 workers exposed to diphenylmethane diisocyanate (MDI). Questionnaire, peak expiratory flow and tests for serum antibodies to MDI–human serum albumin available. An association was found between peak flow rate variability and a questionnaire-based diagnosis of asthma. Three cases of physician-diagnosed OA were identified.

Table 2. (Continued)

First author, date of publication, reference number	Brief publication details
Reddy, 1995 [39]	Respiratory health surveillance and wellness promotion for grain workers. Grain workers (556).
Deacon, 1998 [40]	Respiratory symptoms and ventilatory performance in workers exposed to grain and grain-based food dusts. Workers (570). All symptoms associated with lung function abnormalities.
Cullinan, 1994 (flour) [42]	Work-related symptoms, sensitization and estimated exposure in workers not previously exposed to flour dust. Two hundred and sixty-four new workers included. Reported ≥ 1 work-related symptom (22%). The frequency of new symptoms increased with exposure intensity, and only a weak relationship between the presence of symptoms and having a positive skin prick test to flour was identified. Symptoms were increased in smokers and atopic individuals.
Calverley, 1995 [43]	Study of platinum salt sensitivity in refinery workers. New workers (78). At 24 months, 41% had a diagnosis of platinum salt sensitivity made using differing approaches. The risk of this sensitization was much higher in smokers and those with high platinum exposures.
Bohadana, 2011 [44]	Study of apprentice bakers and hairdressers, with relevance to eNO as a health surveillance tool. One hundred and twenty-six apprentice workers were included. Twenty-nine workers had abnormal results of surveillance tests (four with high eNO and airways obstruction), 15 with high eNO and 10 with airways obstruction alone. Mean eNO was increased in atopic non-smoking apprentices in comparison with atopic smokers and non-atopic subjects. Smoking, a personal history of allergies, the FEV ₁ /FVC ratio and self-reported respiratory symptoms were the main determinants of eNO. The authors concluded that eNO measures in this group might provide addition information on airway inflammation not provided by lung function.
Olin, 1999 [45]	A study of eNO in bleachery workers ($n = 56$) from a Swedish pulp mill. Multiple regression analysis only reported only a history of ozone gassings as associated with elevated eNO.
Lund, 2000 [46]	Study of the utility of eNO as a marker of airway inflammation in aluminium potroom workers. Elevated levels were found in non-smokers, and the authors noted that elevated levels might be a useful marker of early airway inflammation.
Gordon, 1997 [50]	The utility of screening questionnaires was assessed in a flour-exposed population. The authors concluded that these might underestimate the prevalence of asthmatic symptoms, and as a consequence such should not be used alone in workplace screening for OA.
Stenton, 1993 [51]	Shipyard worker-based study. The sensitivity and specificity of various measured values were assessed. The authors concluded that questionnaire recorded symptoms (wheeze, chest tightness, undue coughing or abnormal breathlessness) had a low sensitivity for detecting definite or possible asthmatic activity as judged by airway reactivity and a moderate specificity. It was felt that 'caution is needed when interpreting the results of questionnaires and measurements of ventilatory lung function in the diagnosis of asthma among working populations'.
Gannon, 2005 [52]	Review article and description of an in-house service. The goals of this health surveillance programme were 'prevention, early detection and mitigation of effect of key endpoints, especially asthma and to a lesser degree dermatitis, in people who are occupationally exposed, or potentially exposed, to isocyanates and products containing isocyanates'.
Tarlo 2005 [55]	Review article
Tarlo 2010 [56]	Review article
Smedley, 1996 [57]	NHS Occupational Health departmental audit (78); variable provision of health surveillance for staff potentially exposed to respiratory sensitizers. Lack of policies and guidance also identified.
Other	
Stange, 1996 [48]	Possible health risks from low-level exposure to beryllium.
Suardi, 1994 [49]	Health survey of workers occupationally exposed to cobalt.

All quoted demographic details and basic smoking and occupational data, such as job title and duration of employment, and four of the five articles included information on some measure of cumulative exposure.

Lung function measures

All papers identified reported the use of lung function, with differing values being studied and used as endpoints, mostly based around the measurement of absolute and percentage predicted FEV₁ and the FVC and included use of (i) cross-sectional measures of FEV₁ and FVC and within shift changes in values, (ii) longitudinal change in lung function, (iii) the FEV₁/FVC ratio less than the 5th percentile, as a definition of COPD [14] and (iv) the standardized residual of the FEV₁ <1 [15].

All studies used a validated and accepted standard for spirometry measurement. Meijer *et al.* [14] used the FEV₁/FVC ratio <5th percentile as the definition of COPD, noting that diagnosis in 6.7% of the exposed population and 2.7% of non-exposed controls.

Two studies assessed longitudinal lung function change. The first [16], based in female ceramic workers, identified that lung function decline was associated with duration of employment. The presence of a radiological abnormality was also associated with lung function decline after adjusting for duration of exposure and tobacco smoking.

The second [17], based in china clay workers identified lung function decline to relate to age and smoking status, although again radiological abnormality also related to lung function decline. The authors estimated that a change of one major radiological category was equivalent to approximately 6 years of ageing when assessing effect on FEV₁.

Radiology

Four of the five [15–18] identified articles included information on chest radiographic appearance, radiographs generally being reported by the US-based National Institute of Occupational Safety and Health (NIOSH) approved B readers or equivalent. Forastiere *et al.* [16] noted that where a NIOSH approved B-reader had reviewed radiographs, two were upgraded from grade 1/0 to 1/1.

All papers used the International Labour Organization (ILO) guidelines [20] for interpretation, although the threshold for significant radiological abnormalities differed between papers. For example, Forastiere *et al.* and Rundle *et al.* used ILO 1/0 (or 'major category 1') [16,17], while Suarathana *et al.* used ILO 1/1 as the definition of significant silicosis. The prevalence of ILO grade ≥1/0, in the three studies where this information was available, was 10, 10 and 1.4%, respectively.

Zuskin *et al.* identified that the mean ILO scores were no different between the silica-exposed group and

controls [18], and Rundle *et al.* found the prevalence of ILO major category 1 (essentially ILO grading ≥1/0) to be >6% in the non-exposed group [17].

Rundle *et al.* did estimate that on average it would take a non-smoker an overall silica exposure of 85 mg/m³y to reach ILO grade 1/0 (this equates, for example, to 42 years of exposure at a level of 2 mg/m³) [17].

Respiratory symptoms were generally associated with lung function abnormalities, but not independently with radiographic abnormalities consistent with silicosis. The outcome 'unhealthy' to the question 'How would you assess your recent health condition?' independently predicted the presence of ILO profusion category ≥1/1 consistent with silicosis. [15]

Additionally, the presence of work-related lower respiratory symptoms (WRLRS) was associated with the presence of COPD (as defined by a FEV₁/FVC ratio <5th percentile) [14]. As one might expect, age, duration of employment, years of exposure and job title (or area) were all generally associated with reporting respiratory symptoms in this group, lung function abnormalities (including COPD) and pneumoconiosis.

Suarathana *et al.* identified that 86% of workers with ILO grade ≥1/1 had worked in the silica-exposed industry for more than 15 years, with a mean duration of employment of 25 years, and a minimum duration of employment of 8 years [15]. Forastiere *et al.* found that the risk of silicosis increased with duration of exposure; the odds ratio (OR) for the presence of silicosis being 2.0 for 15–19 years of exposure in comparison to lower levels of exposure but increasing to an OR of 26.0 for greater than 25 years of exposure. This effect appeared to be influenced by starting relevant employment prior to 1970 [16].

None of the publications identified described a validated and evidence-based approach to health surveillance for silica-exposed workers.

(ii) Obstructive lung diseases, excluding asthma

Four papers were identified that dealt with health surveillance in the context of obstructive lung disease. Three of these papers dealt with occupational COPD, or 'COPD with a significant occupational contribution' [14,21,22], and the fourth, the flavouring manufacturing industry, following the discovery of clusters of cases of obliterative bronchiolitis (OB) attributed to diacetyl exposure.

These have been grouped in the context of health surveillance for obstructive lung disease purposes, given the relatively irreversible nature of the two diseases, although there are fundamental differences between the two disease endpoints.

Questionnaire and occupational history

All papers used demographic and questionnaire data; the three papers by Meijer *et al.* used a modified version

of the BMRCRQ [19], including questions on the work relatedness of respiratory symptoms. The paper summarizing OB development following diacetyl exposure used a CDPH/ATS- (California Department of Public Health/American Thoracic Society) based questionnaire with modifications [23].

Lung function measures

Lung function measures (FEV₁ and FVC primarily) were measured in both the COPD and OB-related studies, although the lung function data was used diagnostically in the OB group and as a screening measure in the COPD group.

In those with COPD, there was a predictable excess of any WRLRS (OR 3.6), shortness of breath (SOB, OR 3.2), wheeze (OR 2.5), allergy (concrete workers only) and (by definition) abnormal lung function (OR 3.6, defined as an FEV₁/FVC ratio <5th percentile), compared to those without COPD. Overall, levels of chronic non-work related respiratory symptoms were similar in exposed and non-exposed workers [21].

Lung function abnormalities were found to be associated with silica, concrete dust and rubber exposure, tobacco smoking and a self-reported history of allergy [14,21,22].

In the OB group, obstructive lung function was measured in a similar proportion to that expected in the general population, but there was an excess of severe obstruction and young individuals within this group [23]. Most suspected cases of OB underwent further reversibility testing with bronchodilators and, where available, generally noted an irreversible obstructive lung disease.

(iii) Asthma (26 articles)

Twenty-six articles were identified that related to either OA or occupations commonly associated with an increased risk of OA. These are either discussed in this section or cited in the discussion. These covered a diverse range of occupations and potential exposure to allergens, including laboratory animal workers [24–26], bakers [27], motor vehicle repair work [28] and platinum refining [29].

Questionnaire and occupational history

The majority of questionnaires described recorded respiratory symptoms (both generic and work related), occupational and demographic data, usually in the form of a validated respiratory questionnaire, with modifications to include questions about work relatedness of symptoms; the most common basis for this was the BMRCRQ, though both the International Union Against Tuberculosis & Lung Diseases (IUATLD) [30] and National Health and Nutrition Examination Survey II (NHANESII) [31] questionnaires were used.

While strictly relating to referrals from a health surveillance programme to detect cases of isocyanate asthma, Kraw *et al.* [32] described their respiratory questionnaire as highly sensitive for identifying such cases. In addition, it was identified that no further cases of OA were identified with spirometry in the absence of questionnaire findings. Full data from the underlying larger study population were not presented in this article, however, and no information was provided about levels of nasal or non-specific respiratory symptoms or early loss of lung function.

Brant [27] compared responses with a research questionnaire with data derived from an occupational health department in the same group of flour-exposed workers. The origin of the research questionnaire used was not cited in detail, although it was evident that routine health surveillance carried out in-house appeared to underestimate respiratory end points in comparison to those identified by the research study. By contrast, Allan [26] *et al.* described the use of an IUATLD-based questionnaire that identified responses in laboratory animal workers that were broadly consistent with those documented by the occupational health provider.

Murphy *et al.* [33] also raised the important issue of questionnaire administration in the health surveillance context, noting that high levels (55% of questionnaires) were inappropriately self-administered rather than interviewer-administered. However, no data were given in relation to how these types of administration may lead to differing responses.

Mackie *et al.* [28] used an adapted BMRCRQ-based questionnaire in the large reported series of workers exposed in the motor vehicle repair sector. The details of this study will be dealt with below.

Labreque [34] and colleagues described their experience with health surveillance in a group of isocyanates-exposed workers. Using an IUATLD-based questionnaire, the process identified possible cases of OA by using three positive responses to the questionnaire as a threshold for further assessment, although no details were given of the specific nature of these questions. Those identified to have OA were subject to a reduction in their workplace exposures with a consequent improvement in their airway reactivity, with some being rendered non-reactive. While it is not entirely clear whether measures of lung function were also used as part of the screening process, the authors concluded that a brief self-administered questionnaire could be used for such an approach, although the questionnaire used required further validation.

Johnston [35] studied a group of farmers using an adapted questionnaire, adding a question relating to general health. Self-rated health as good or excellent did appear to assist prediction of airways obstruction in this group, although its use to predict early occupational respiratory disease was not discussed. Abnormal levels

of lung function in this group were common; the FEV_1 was <80% of predicted value in ~20% of those tested, and the authors also consequently raised the issue of whether all workers were fully reporting their respiratory symptoms.

Lung function measures

Lung function use was commonly reported in the papers identified, with 12 studies using at least basic lung function data. A small number of studies used non-specific, or specific, bronchial challenge testing. Certain of these also assessed various forms of longitudinal lung function [36,37].

Ott *et al.* [36] described a health surveillance process for isocyanate-exposed workers and were able to carry out lung function measures that complied with acceptability criteria in the majority of cases, with only 14% deemed unsatisfactory for a number of reasons. While cases of OA related to exposures were identified, this work did not identify a strong relationship between isocyanate exposures and lung function decline. It is not clear from the data which surveillance tool used was responsible for identifying those with subsequently confirmed OA.

Senthilselvan *et al.* [37] reported a longitudinal study of grain-exposed workers and identified, using a standard Labour Canada questionnaire, that persisting wheeze (and particularly new onset wheeze) was associated with the largest mean annual rate change in FEV_1 , although numbers with OA were not reported.

One study in particular reported the use of lung function to benchmark severity of lung function abnormalities prior to and after introduction of health surveillance. In this workplace, health surveillance appeared to lead to the detection of less severe OA as judged by the level of measured airway hyper-responsiveness [34].

Bernstein [38] reported the use of a respiratory questionnaire, lung function, serial PEF and tests of immunology to assess workers exposed to diphenylmethane diisocyanate. Three workers were confirmed to have physician-diagnosed OA, one of which where the diagnosis was based solely on lung function abnormality and bronchodilator response (immunologic tests were neither sensitive nor specific for a diagnosis of OA in this group).

Again, data from Allan [25] relating to laboratory animal workers identified that 80% of the lung function testing in the workplace was able to satisfy acceptability criteria, and that of the three cases of possible OA that were identified, none was identified by spirometry abnormality alone.

Two studies (Deacon *et al.* and Reddy *et al.*) [39,40] found no predictive effect of work within grain and grain-based food production on reported respiratory symptoms as measured by questionnaire after correcting for smoking and obesity. Both these studies report data from in-house surveillance schemes reported by the occupational health provider.

Murphy *et al.* also raise the issue of using multiple lung function testing machines in the workplace, an issue that is dealt with comprehensively in the current ACOEM guidance [41] for spirometry in the workplace.

Immunology

Cullinan [42] and co-workers investigated a group of flour-exposed workers using a combination of respiratory questionnaire and measures of specific sensitization to a variety of flour-related allergens. Measures of lung function were not reported; although they identified that symptoms related to flour dust exposure intensity and that sensitization to wheat flour and fungal alpha amylase related to increased exposure, although this relationship was confounded by atopy.

Related work by the same research group [24] in workers exposed to rat allergen again identified a relationship between the onset of new work-related symptoms and exposure, and a relationship between sensitization and exposure. Again, no lung function data were reported. In neither case was the questionnaire used identified more specifically and presumably represented an in-house research questionnaire.

Merget *et al.* [28] identified a strong relationship between conversion to a positive skin test and the development of respiratory symptoms in a small group of platinum workers. No changes in lung function or airway reactivity were noted, and comments were also made about skin tests becoming negative following reduction in exposure. These findings are consistent with previous work supporting the use of a positive skin prick test in this group as a strong predictor of future symptoms.

The study by Brant *et al.* [27], already described above in part, used a combination of work-related symptoms and the presence of specific sensitization to flour as a working definition of OA in their study, as the study was not designed to allow more comprehensive clinical assessment of workers.

Exhaled nitric oxide

Bohadana *et al.* [44] described their experience with exhaled nitric oxide (eNO) as a tool within a health surveillance programme for bakers and hairdressers and identified significant differences between information derived from each parameter. Of 29 possible cases of OA, abnormal spirometry identified 10 and a further 15 were identified using eNO. This group also used a cut-off point for the FEV_1/FVC ratio of the 5th percentile of the predicted value for that individual, given that the study group were relatively young.

Data relating to the utility of eNO were also identified in aluminium potroom workers and pulp-mill workers [45], although the latter specifically relate to identifying consequences of gassings with irritant gases and consequently will not be discussed further here. Lund *et al.*

[46] report the use of eNO as an early marker of asthma in aluminium potroom workers. A previously validated questionnaire [47] was used to record demographic and questionnaire data, and eNO values appeared to relate to exposure in non-smokers, and also to the presence of asthma-like symptoms. The data supplied by the authors, however, did not allow further clinical characterization of workers, did not identify those with OA and did not discuss how early identification of asthma might lead on to workplace interventions.

Mackie [27] assessed the overall efficacy of a national motor vehicle repair sector health surveillance programme. Questionnaire responses and lung function tests were used to identify those workers who required further assessment, although the actual combinations of symptoms or lung function abnormalities used were not defined. A paper review by an occupational health provider was then carried out on the vast majority of the identified cases of concern, with only a small number of workers referred for specialist assessment. Approximately half of workers referred to their GP for further assessment subsequently failed to keep this appointment. Of those referred to an occupational respiratory specialist only 63% attended.

Mackie additionally concluded that while health surveillance was potentially able to identify early cases of OA, there were problems associated with referral to and subsequent attendance at either GP or specialist appointments. It was felt appropriate that communication could be improved between occupational health and primary care professionals, with attention to better mutual understanding. Additionally, closer working between occupational health providers and specialist physicians in either occupational medicine or occupational respiratory medicine was identified as a future development.

(iv) Other lung diseases (two articles)

Two papers dealing with other respiratory diseases were identified as part of the initial search (chronic beryllium disease [48] and hard metal disease [49]). Each dealt with an uncommon respiratory disorder, each with specific issues relating to health surveillance particular to the unusual nature of the respective diseases. Both used a combination of respiratory questionnaire and lung function, with additional use of lymphocyte proliferation testing for beryllium exposed workers. The details of these papers are not interpreted further given their limited scope to comment on general respiratory health surveillance.

(v) Modelling comments

Several studies were identified that applied mathematical modelling approaches to respiratory health surveillance. Data derived from surveillance of laboratory animal-exposed workers utilized modelling in order to

stratify workers into risk categories for subsequent sensitization to an array of relevant allergens. Meijer *et al.* [24] described such a process, using reported symptoms as well as other basic information (including gender, wheeze, allergic symptoms and hours worked with rats per week). The approach involved the development of a prognostic and a diagnostic model for these workers. Total IgE, as well as IgE to common allergens, was associated with future specific sensitization to laboratory animal allergens, although the authors conceded that the proposed threshold values for risk scores formulated would not identify the majority of sensitized individuals.

The same group has developed a risk model for COPD (not specifically occupational related COPD), using similar personal and exposure data [19]; additionally Suarathana *et al.* have developed a prediction model for silicosis. Already described in part above, this model identified age, smoking habit, job title, duration of employment, self-rated health and FEV₁ as potential predictors for the development of silicosis [15]. This model was also able to suggest an approach to potentially limit the number of silica-exposed workers requiring surveillance chest radiographs, while balancing this against the numbers of cases that would be missed.

Discussion

Respiratory health surveillance was not standardized within respiratory disease groupings. Differing approaches and frequencies of surveillance were utilized across workplace sectors and consisted of a combination of a respiratory questionnaire, lung function, radiology and other tests, including immunological markers and markers of airway inflammation.

The use of a respiratory questionnaire was common, and generally consisted of a modified version of either the BMRCQ, CDPH/ATS, International Union Against Tuberculosis & Lung Diseases (IUATLD) or NHANESII questionnaire. Additional questions were discussed, although details of their sensitivity and specificity were not given, and neither had their performance been reported in other working populations.

While respiratory questionnaires were generally accepted as an important part of respiratory health surveillance, further standardization and improved validation against important health outcomes is desirable. In addition, various authors have highlighted problems with questionnaire use.

For example, Gordon [50] *et al.* and Brant *et al.* [27] raised issues relating to questionnaire reliability. Given that positive responses to questionnaires may lead to further medical investigations for workers, the outcomes of which may place employment at risk, it was suggested that completion might not always be accurate. Presumably the extent to which workers are handled appropriately following a failure of health surveillance

will also vary between employers, industry sectors and also geographically. Stenton *et al.* [51] have also previously suggested that questionnaire responses may have low sensitivity to detect clinical endpoints, including airway hyper-reactivity.

Nevertheless, the respiratory questionnaire remains an important tool. Further work might include the development of a core set of questions, with additional components according to the nature and extent of respiratory hazards and their risks, in addition to educational material to improve overall surveillance programme success [52].

While lung function measures were commonly used and reported as part of the health surveillance approach, most commonly being measurement of the FEV₁ and FVC, various issues were raised. It was unclear whether absolute values of FEV₁/FVC ratio should be assessed as abnormal only when a fixed value is reached (normally <0.7) or whether, particularly in younger workers, the 5th percentile of a predicted value for each worker should be used [39]. In other words, using a fixed cut-off of 0.7 for this ratio, while easy and simple to recall and calculate, may misattribute normal individuals into abnormal groups in more elderly populations, and in younger workers will fail to identify abnormal airway function until it is relatively advanced.

Similarly, no data are available to inform longitudinal interpretation of FEV₁ decline, although it appears sensible to suggest further work here, while also using serial lung function to help identify those workers who may be declining faster than expected. The use of freely available software (such as SPIROLA) to plot and interpret such declines may assist.

It would also appear sensible to identify thresholds in both cross-sectional and longitudinal lung function decline that would trigger an onward referral for further specialist assessment, as would ensuring that the accuracy of workplace-based spirometry programmes are optimized, given that inaccurate spirometry measurements may delay identifying those with early occupational respiratory disease [53].

While certain publications have suggested that the role of lung function in surveillance is uncertain [54], the evidence assessed generally support their inclusion. There have been no reported studies directly comparing the use of questionnaires alone or in combination with lung function. Additionally, lung function assessment also supplies an objective measure, which may be useful specifically in populations that may be concerned to report respiratory symptoms. This view is also supported by various authors with practical health surveillance experience [55–57].

The role of more specialized pulmonary function tests, such as specific and non-specific tests of bronchial hyper-responsiveness, is less clear, and their use is currently predominantly confined to specialist diagnostic

testing [54]. Similarly, the use of eNO cannot be recommended as a regular addition to health surveillance, although data may be generated in future that allows for further assessment of its benefits and limitations. Data from aluminium potroom workers, pulp-mill workers, bakers and hairdressers support further research of its utility and suggest that this measure may give further information about airway inflammation not identified from more standard surveillance tools.

There are little data to support the use of routine chest radiographs in respiratory health surveillance outside those industries traditionally associated with a risk of pneumoconiosis, and in particular for workers exposed to respirable crystalline silica. Regarding the latter, no consensus exists in relation to its content and frequency. Further work here is vital in order to allow the least-intrusive and most-sensitive programme to be developed. A summary of current evidence is available [58].

Immunological markers of sensitization were useful in certain settings, most notably in platinum refining, where sensitization was related to the future development of symptoms [28]. The more widespread use of more general tests of sensitization, such as flour specific IgE, will depend on their quality, availability, costs and a better understanding of their sensitivity and specificity for identifying early disease.

Finally, mathematical models have been used to assist identification of workers with the highest risk of progressing to either sensitization to an allergen, the development of an allergic disease, or the development of silicosis. The effectiveness of these approaches is likely to be tested in future workplace-based studies.

There are a number of weaknesses of approach for this review. It is possible that relevant research has been excluded, either at the search or at the initial review stage. The intent of the review was, however, to identify publications dealing with the specifics of carrying out respiratory health surveillance, rather than dealing with the more general issue of causation of occupational respiratory disease. Inevitably, therefore, certain partly relevant evidence may have been excluded if its primary intent was not to deal specifically with the health surveillance process. Grey literature was not assessed and may also contain relevant information. These issues may have applied to current topical areas of interest, including early identification of COPD and other less common conditions including extrinsic allergic alveolitis. Coal mining literature was not included; while six articles were identified in the initial search, none was deemed appropriate for inclusion given the specific intent of the review.

Additionally, the strength of the evidence, while not formally assessed, was what might be expected for a review of such material. Studies were generally case series, or cross-sectional workplace based, with no higher quality evidence such as seen with randomized approaches.

Respiratory health surveillance remains a relatively disparate process that would benefit from a greater standardization of approach. In addition to standardizing tools used for surveillance, development of associated multidisciplinary educational and training approaches for all involved has the potential to improve its uptake and quality.

Key points

- A variety of respiratory questionnaires were used for health surveillance, and no single standardized approach was identified. A core set of health surveillance questions could be developed, with additional question modules to help identify specific respiratory diseases.
- Lung function measures were commonly recorded in health surveillance, most specifically the forced expiratory volume in 1 s and forced vital capacity. Most reported percentage predicted values. As the forced expiratory volume in 1 s/forced vital capacity ratio falls with age, the lower limit of normal for this value should perhaps be considered more useful than a single cut-off of the percentage predicted (e.g. the commonly used 0.7 value of this ratio).
- It is possible to generate accurate lung function measurements in the workplace. There are good summary documents available to guide this process.
- Changes in lung function over time were assessed and are potentially useful in a variety of settings. Software is available to assist their interpretation.
- Chest X-rays were only reported as used for silica-exposed workers. There is no agreed strategy for the health surveillance of this group.
- Immunological tests (serum IgE and skin tests) are helpful for a small number of potential allergen exposures, including bakery exposures, laboratory animal workers and platinum salts. Better knowledge of their sensitivity and specificity will improve their utility.
- Mathematical modelling is now being applied to respiratory health surveillance data, and these techniques may improve the design of such programmes in the future.
- The role of newer tests, such as exhaled nitric oxide, remains unclear in respiratory health surveillance.
- While raised as potentially important, evidence-based training packages or educational materials to assist with respiratory health surveillance were not identified.

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Conflicts of interest

None declared.

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OCCUPATIONAL MEDICINE CALENDAR

Date	Event	Contact Address	Venue
September 9–11	Ninth International Symposium on Biological Monitoring	email: kate.jones@hsl.gov.uk http://www.isbm2013.org.uk/	Manchester
September 11–14	Association of Occupational Health Professionals in Healthcare (AOHP) Conference	http://www.aohp.org/pages/about_aohp/contact_us.html	Orlando, FL
September 12–13	Work & Well-Being 2013	http://wwb2013sf.eventbrite.com	San Francisco, CA
September 18	Partnership for European Research in Occupational Safety and Health	http://www.perosh-seminar2013.org	
September–November	Certificate in Cognitive Behavioural Therapy Skills for OH Professionals	http://www.atworkpartnership.co.uk/conferences/CBT/index.php	London
October 1	Trent Occupational Medicine Annual Meeting	www.tom-cme.org.uk	Nottingham
October 6–10	The 61st International Congress of Aviation and Space Medicine (ICASM 2013)	http://www.icasm2013.org	Jerusalem, Israel
October 8 & 9	Workplace Health 2013	http://www.atworkpartnership.co.uk/conferences/workplace_health/	Warwickshire
November 4–8	21st International Symposium on Shiftwork and Working Time	email: shiftwork2013@usp.br http://www.fsp.usp.br/shiftwork2013	Sauipe Park, Bahia State, Brazil
November 5–8	A+A 2013—Safety, Security and Health at Work	email: messeduesseldorf@germanchamber.ca http://www.messe-duesseldorf.de	Dusseldorf, Germany
November 13–15	Certificate in OH Case Management	http://www.atworkpartnership.co.uk/conferences/case_management/index.php	London
2014–2016 April 27–30, 2014	American Occupational Health Conference (AOHC)	http://www.acoem.org/educational_conferences.aspx	San Antonio, TX
August 7–14, 2014	American Psychological Association 2014 Annual Convention	www.apa.org	Washington, DC
October 19–22, 2014	7th International Symposium Safety & Health in Agricultural & Rural Populations: Global Perspectives (SHARP)	email: cchsa.symposium2014@usask.ca	Saskatoon, Canada
May 3–6, 2015	AOHC	http://www.acoem.org/educational_conferences.aspx	Baltimore, MD
May 31–June 5, 2015	31st International Congress on Occupational Health	email: overseas@kosha.net http://www.icoh2015.org	Seoul, South Korea
April 10–13, 2016	AOHC	http://www.acoem.org/educational_conferences.aspx	Chicago, IL