Application of a dynamic population-based model for evaluation of exposure reduction strategies in the baking industry

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Abstract. Recently a dynamic population model was developed that simulates a population of bakery workers longitudinally through time and tracks the development of work-related sensitisation and respiratory symptoms in each worker. Input for this model comes from cross-sectional and longitudinal epidemiological studies which allowed estimation of exposure response relationships and disease transition probabilities This model allows us to study the development of diseases and transitions between disease states over time in relation to determinants of disease including flour dust and/or allergen exposure. Furthermore it enables more realistic modelling of the health impact of different intervention strategies at the workplace (e.g. changes in exposure may take several years to impact on ill-health and often occur as a gradual trend). A large dataset of individual full-shift exposure measurements and real-time exposure measurements were used to obtain detailed insight into the effectiveness of control measures and other determinants of exposure. Given this information a population wide reduction of the median exposure with 50% was evaluated in this paper.

1. Introduction

Exposure to flour dust and related enzymes is one of the most common occupational exposures associated with the development of occupational respiratory symptoms especially occupational asthma [1, 2]. Recently several studies reported no or only a small decreasing time trend in occupational exposure to flour dust and fungal α-amylase [3, 4]. These observations indicate the need for an evidence base for effective interventions to decrease occupational exposure to flour dust and as a result the prevalence of respiratory diseases.

In the Netherlands a health surveillance system was recently installed in all major flour processing industries as part of a covenant to monitor the disease status of the population [5]. In addition, several large exposure measurement studies were conducted that provide detailed information on exposure levels and determinants of exposure including control measures [4, 6, 7]. The information from the health surveillance system in combination with the exposure data was used to develop a dynamic population-based model. This model can be used to simulate a population of bakery workers
longitudinally through time and tracks the development of work related sensitization and respiratory symptoms in each worker related to their exposure. This model enables (prospective) health impact assessment of different intervention scenarios and can provide insight in the impact of exposure reductions (or other interventions) on the population burden of disease. This can provide researchers and policy makers with information on trends in disease development in the population resulting from exposure reductions and help decide on the most cost-effective and best achievable intervention strategy.

2. Methodology
Figure 1 gives a graphical representation of the health impact assessment approach as in our study; the cost-benefit analysis is a separate addition that is beyond the scope of this abstract but will be discussed briefly in the presentation.

2.1. The dynamic population-based model
Basically the core of our health impact assessment is the developed dynamic population-based model that integrates the available epidemiological and exposure information, in combination with general population information relevant for the modeled exposure-disease relationship (e.g. atopy, background rates of sensitization, distribution of career length etc.). This model enables the evaluation of the impact of changes in exposure on the disease burden of the population. This might then provide input for a cost-benefit analysis.

![Figure 1. The health impact assessment approach](image)

The development of our dynamic population-based model is described in a paper by Warren et al. [8]. In short, the model simulates a population of bakery workers longitudinally through time and tracks the development of work related sensitization and respiratory symptoms in each worker related to their exposure. The main part is a multi stage disease model that simulates the transition of workers between different disease states. The main states incorporated are work related sensitization to wheat allergens and fungal α-amylase, lower- and upper respiratory symptoms and finally work disability. Disease progression is modelled with a yearly probability that depends upon the workers’ simulated exposure to flour dust and fungal α-amylase. The dose-response slopes for these transition probabilities were estimated using a substantial dataset of bakery workers in the Netherlands [9]. In our model, work related sensitization and atopy are key determinants for the development of respiratory symptoms and upper respiratory symptoms are assumed to generally precede the
development of lower respiratory symptoms. Separate transition probabilities have been estimated for atopic- and non-atopic workers.

2.2. Intervention scenario
We used the model to evaluate the effect of exposure reductions on the development and occurrence of disease in this population. The scenario discussed in this paper involves a population wide reduction in median exposure to flour dust of 50%. A 50% reduction is assumed to be feasible taking into account the state-of-the-art knowledge of efficacy of control measures [7]. For fungal $\alpha$-amylase, direct evidence of efficacy of control measures is lacking, although a very recent time trend analysis does show reductions in amylase exposure in the Netherlands over the past decade [4]. However, no information is available on the associated determinants of this decrease. For this worked example we assume the decrease in fungal $\alpha$-amylase is equal to that of flour dust with a 50% reduction in median exposure at the start of the simulation period. Variability in both exposures is assumed to remain the same over time.

2.3. Simulation
The intervention scenario was simulated by reducing the population median exposure at the time of the intervention (nominally the year 2000) and running the model for 20 years in order to observe changes in disease prevalence. The results from the simulation were used to create trend plots, and to observe the trend in relative prevalence for the different disease states as well as for the healthy population. Confidence intervals for the relative prevalence were obtained through an uncertainty analysis that repeated the procedure within a Monte Carlo algorithm, using random model parameters generated from distributions to represent parameter uncertainty. In the presented results we have aggregated the different disease states into three main disease states; sensitized, work-related upper respiratory symptoms and work-related lower respiratory symptoms.

3. Results
In our scenario the population median exposure decreased by 50%, prior to exposure reduction a geometric mean exposure level of 1.8 mg/m$^3$ for flour dust and 1.0 ng/m$^3$ for fungal $\alpha$-amylase was observed. Figure 2 shows the relative trend in prevalence of our three main disease states, the width of the bands reflects the uncertainty in our estimates of the relative prevalence of the different disease states for a given year.

As can be seen from Figure 2 a downward trend is predicted for all three groupings of disease states with strongest trend for lower respiratory symptoms. The plot also shows that lower respiratory symptoms have the largest associated uncertainty. Another important observation is the fact that although the exposure reductions occurred at the start of the simulation period, the effect of this reduction is still ongoing several years after the introduction. This is most likely caused because complete turnover of a working population takes several decades. Overall we can say that a 50% reduction in exposure will eventually lead to a 35 to 65% reduction in asthma cases after more than a decade, a 20 to 35% reduction of workers with upper respiratory symptoms and 10 to 20% less sensitized workers.
4. Conclusions

The example presented here shows how health impact assessment can use available exposure and epidemiological data to obtain more insight in the relation between exposure reductions (e.g. interventions) and trends in the population burden of disease. The results indicate that the impact on health might develop relatively slow and take several years to take full effect, this is probably associated with the worker population turnover rate. This is important information for both policy makers (who might enforce and monitor these changes) as well as employers and employees who initiate changes in exposure to reduce disease prevalence. Nevertheless it is possible that other more specific intervention scenarios will lead to quicker results. For example exposure reduction in combination with health surveillance might be more effective. This, and other possibilities are explored in another study, the preliminary results of which will be available soon.

The example presented here has some flaws, we decrease the median of the population exposure distribution but assume that variability remains the same. It is much more likely that a hygiene intervention will have a different impact on high and low exposed workers, as was also shown in an earlier paper [7]. This would result in a more drastic change of the population exposure distribution, it will not only shift as is the case in our example, but the variability (e.g. right tail of the distribution) will also decrease. This might change the impact on our disease outcomes. Another simplistic assumption is that exposure decreases all at once at the start of the simulation when, in general, these reductions are much more likely occur in a stepwise manner [3, 10, 11].
As can be seen from our results the uncertainty in our prevalence estimation for lower respiratory symptoms is larger than for the other states. The main reason for this is that the number of cases in our dataset was small. As a result the estimated dose response curve for this disease state had larger confidence intervals resulting in bigger uncertainty in our simulation model. This could be decreased if a larger dataset or good longitudinal information becomes available.

In general the input parameters for the disease model, especially the transition probabilities were estimated using information from a cross-sectional study. Although the use of sophisticated statistical techniques allowed us to do this, longitudinal data with which to check the validity of these parameters are scarce. The general comparisons that we made and also the comparisons of cross-sections of data from our model (data not presented here) with observational studies suggest that the model performs extremely well. Nevertheless it would be preferable to obtain better longitudinal data to perform a more rigid validation of the model.

Overall, we have demonstrated the added value of using health impact assessment especially when planning strategies to prevent occupational diseases. The methodology enables decision makers to weigh different options and also to discuss the implications of the observed trends. In the near future a more elaborate analysis will be presented comparing several different realistic intervention strategies and evaluating the validity of our model in a broader sense.

Reference List

[1] Baur X, Degens PO and Sander I. Baker's asthma: still among the most frequent occupational respiratory disorders. J Allergy Clin Immunol 1998 Dec;102(6 Pt 1):984-97.
[2] Bernstein IL, Chan-Yeung M, Malo JL, Bernstein DI 2006 Asthma in the workplace. 3 ed. (New York, Taylor & Francis Group)
[3] Creely K, Tongeren van M, While D, Soutar A, Tickner J, Bolton A, et al. Trends in inhalation exposure: mid 1980s till present. Suffolk: HSE Books; 2006. Report No.: RR 460.
[4] Meijster T, Tielemans E and Heederick D. The impact on exposure to flour dust and fungal α-amylase among Dutch workers exposed to flour dust: A time trend analysis. submitted.
[5] Meijer E, Suarthana E, Monchy de J, Rooy van F, Rooijakkers J, Meijster T, et al. Diagnostic Research in Occupational Allergy: Results of a nationwide surveillance among bakery workers. In: Suarthana E. Predicting Occupational Lung Disease. Thesis Utrecht: Utrecht University; 2008. p. 89-101.
[6] Meijster T, Tielemans E, de Pater N and Heederick D. Modelling Exposure in Flour Processing Sectors in The Netherlands: a Baseline Measurement in the Context of an Intervention Program. Ann Occup Hyg 2007 Mar 17;51(3):293-304.
[7] Meijster T, Tielemans E, Schinkel J and Heederick D. Evaluation of peak exposures in the Dutch flour processing industry: implications for intervention strategies. Ann Occup Hyg Accepted
[8] Warren N, Meijster T, Heederik D and Tielemans E. A dynamic population-based model for the development of work related respiratory health effects amongst bakery workers. submitted.
[9] Jacobs J, Meijster T, Meijer E, Suarthana E and Heederik DJJ. Wheat allergen exposure and the prevalence of work-related sensitization and allergy. Allergy 2008; Epub ahead of print.
[10] Kromhout H, Vermeulen R. Long-term trends in occupational exposure: Are they real? What causes them? What shall we do with them? Ann Occup Hyg 2000;44(5):325-7.
[11] Miller BG, Cherrie JW, Groat S and Kauffer E. Changes in workplace concentrations of airborne respirable fibres in the European ceramic fibre industry 1987 1996. Ann Occup Hyg 2007 Aug;51(6):501-7.