1. Introduction

There is currently a debate on whether the aerosol exhaled following the use of e-cigarettes has any effect on the health of bystanders.

We previously developed an air quality model based on a series of equations describing the relationship between the concentration of nicotine in the indoor air from intermittent use of an e-cigarette, the release rate and the factors affecting the dispersion and dilution in the indoor air. Such factors considered include the volume of the indoor environment, the effective air exchange rate and the role of nicotine loss due to surface deposition. The current work builds upon the air quality model presented previously at the Global Forum on Nicotine Conference, Poland 2014 [1].

We used this model to predict bystander exposure to nicotine in the ambient air using data on exhaled cigarette smoke at a simulated e-cigarette user.

When developing the model a number of parameters were considered including:
- distance of the e-cigarette user relative to the bystander;
- quantity of nicotine in the exhaled aerosol;
- speed of exhaled aerosol nicotine deposition and direction of the bystander;
- indoor air exchange rate;
- speed of exhaled aerosol nicotine deposition.

Here we consider the contribution each of these parameters has on the level of nicotine in the indoor air and therefore bystander exposure.

2. Phases of bystander exposure to exhaled e-cigarette aerosol after a single ‘puff’: model output

When an e-cigarette user takes a ‘puff’, the nicotine-containing aerosol is inhaled and a fraction of nicotine is retained by the user. The remaining aerosol is then exhaled, where it is subject to passive exposure and the initial phase of bystander exposure.

Using the air quality model, four distinct phases of bystander exposure are identified following a single ‘puff’ and exhalation event (Figure 1). The model output is characterised by a peak in nicotine concentration when the exhaled aerosol first reaches the bystander then declines due to aerosol propagation, dilution and any potential surface deposition of nicotine.

Phases of bystander exposure to exhaled aerosol

Phase 1, e-cigarette user takes a single ‘puff’, the nicotine-containing aerosol and exhaled cigarette aerosol into the air which propagates in all directions until it is not yet exposed to nicotine in the ambient air.

Phase 2, the indoor air exchange begins. There is a reduction in the concentration of nicotine at the bystander’s position caused by a combination of factors including aerosol propagation, air advection and any surface deposition of nicotine.

Phase 3, the indoor air exchange continues. The nicotine concentration at the bystander’s position continues to decline as a result of further advection of air and any surface deposition of nicotine.

Phase 4, there is a continued reduction in the concentration of nicotine in the ambient air at the bystander’s position.

3. Parameters influencing the concentration of nicotine in the indoor air at the bystander’s position

Our model considers a number of parameters including:
- (i) the distance from the bystander to the e-cigarette user;
- (ii) the speed of exhaled aerosol propagation (in the direction of the bystander);
- (iii) the speed of exhaled aerosol nicotine deposition (in the direction of the bystander);
- (iv) indoor air exchange rate;
- (v) speed of exhaled aerosol nicotine deposition.

Here we consider the contribution each of these parameters has on the level of nicotine in the indoor ambient air and therefore bystander exposure.

4. Effect of varying all model parameters on bystander exposure

In Section 3 we evaluated the impact of varying a single parameter in the model on the concentration of nicotine in the ambient air at the bystander’s position. Here, we explore the collective effect of varying all five parameters concurrently over an 8 hour working day (including a 1 hour lunch break) in a 37.5 m² office where the e-cigarette user takes a single ‘puff’ once every five minutes.

A dataset was generated by assigning each parameter within the model three values, “low (L); medium (M); and high (H)”, resulting in a total of 243 (3²) unique scenarios which collectively predicts the range of average nicotine concentrations in ambient air over 8 hours in the workplace. Figure 3A demonstrates that across all 243 scenarios, the lowest average 8 hour nicotine concentration ([Nicotine]L) in the ambient air was 0.2 µg/m³ (where nicotine concentration in the bystander’s direction) and the highest average 8 hour nicotine concentration ([Nicotine]H) in the ambient air was 2.0 µg/m³ (where nicotine concentration in the bystander’s direction) levels of nicotine exhaled, L: speed of exhaled aerosol nicotine deposition in the bystander’s position, H: speed of exhaled aerosol nicotine deposition, L: distance from e-cigarette user, H: indoor air exchange rate, L: the UK Health & Safety Executive states that the average 8 hour workplace exposure limit (WEL) for nicotine is 500 µg/m³ [2].

The data from the above figure was subsequently arranged and displayed graphically as a box plots to elucidate the impact that each parameter has on the calculated range of average 8 hour nicotine concentrations (Figure 3B). For example, to examine the impact of changing the distance from e-cigarette user the 243 scenarios were grouped where “distance from e-cigarette user” was constant (i.e. low (81 scenarios), medium (81 scenarios) and high (81 scenarios). Changes in the maximum average 8 hour nicotine concentration between the “low” and “high” parameter values were used to assess the impact that “distance from e-cigarette user” has on the calculated range of average nicotine concentrations.

All model parameters had an impact on the maximum 8 hour nicotine concentration in the ambient air. An increase in the “quantity of nicotine exhaled” or “speed of exhaled aerosol propagation in the direction of the bystander” resulted in an increase of 67% or 26% in the maximum average 8 hour nicotine concentration in ambient air at the bystander, respectively. An increase in the “speed of exhaled aerosol deposition”, “indoor air exchange rate” or “distance from e-cigarette user” resulted in a 32%, 40% or 25% reduction in the maximum average 8 hour nicotine concentration in ambient air at the bystander, respectively. In all cases, the maximum average 8 hour nicotine concentration in ambient air at the bystander was significantly lower than the UK WEL for nicotine.

The most important model parameter identified with regard to bystander exposure was found to be the “quantity of nicotine exhaled”. Therefore, it is essential that precise measurements are made regarding the quantity of nicotine retained by the e-cigarette user, i.e. the fraction not exhaled into the ambient air, when determining bystander exposure to nicotine in exhaled e-cigarette aerosol.

5. Conclusions

In our model we demonstrate that the parameters which impact the calculated range of bystander exposure to nicotine the most are the “quantity of nicotine exhaled”, “speed of exhaled aerosol nicotine deposition” and the “indoor air exchange rate”.

The output of the model may be improved by refining the values assigned to the input parameters through experimental studies e.g. quantification of nicotine retention. We are working towards that goal. Studies which attempt to assess bystander exposure to nicotine from exhaled e-cigarette aerosol should be conducted whilst e-cigarettes are being smoked. Nicotine detection at the bystander may provide misleading conclusions.

Bystander exposure to other exhaled aerosol components may be estimated using this model.

Comparison of model outputs with experimental results will enable refinement and validation of the model. Together, appropriately validated models and robust experimental studies may assist in the development and implementation of evidence-based regulation.

Declaration

All authors are employees of Imperial Tobacco Group.

References

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