Physical characteristics of cigarette smoke and e-cigarette aerosol, inhalation conditions and their implications for dose

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Cigarette smoking produces a complex and dynamic condensation aerosol from a supersaturated vapour generated by processes of combustion, pyrolysis and distillation. Electronic cigarettes (e-cigarettes) also produce a dynamic condensation aerosol by rapidly evaporating a simpler formulation containing nicotine and water with glycerol, propylene glycol (PG) or a mixture of each.

Areas of regulatory interest may include the nature and consistency of the device output including droplet size and concentration, and how these impact on delivered and retained dose of the formulation components.

Droplet size distributions were measured by electrical mobility (EM: Model DMS-500 MkII, Cambustion, UK) and by laser diffraction (LD: Spraytec, Malvern, UK). The Smoking Cycle Simulator (SCS: Cambustion, UK) was used to generate appropriate puff profiles and to minimise dilution and potential droplet evaporation.

Volume-weighted median droplet diameters (d_{50}) for e-cigarette aerosols were typically less than 500 nm by LD and less than 300-400 nm for EM, versus equivalent tobacco smoke measurements of approximately 150-210 nm. Precision data were product dependent but less than 4–5% for most e-cigarette products. This degree of precision meets the acceptance criteria for droplet size distribution (d_{50} ± 20% for d_{50} < 1 µm) for laser diffraction measurements (e.g. European Pharmacopeia, 2010) for similar aerosol products. Precision data were similar for tobacco products on a per cigarette basis, but diameter decreased puff by puff along the tobacco rod due to reducing time for coagulation (Adam *et al*, 2009).

Droplet concentration data for cigarettes and e-cigarettes were typically of the order of 10^9.cm^{-3} at the point of generation such that early behaviour is dominated by coagulation. This supports the hypothesis that the aerosol chemistry will be homogenous for both cigarette smoke (Li *et al*, 2014) and e-cigarette aerosol, although the latter is significantly less complex.

The dynamic physical and chemical changes of the droplets during puffing, mouth-hold and within the lungs during inspiration and expiration are subsequently described by the aerosol dynamics model ADiC (Aerosol Dynamics in Containments), which considers coagulation, conductive and convective heat transport, diffusive and convective vapour transport, phase transition and particle deposition (Pichelstorfer *et al*, 2013). This aerosol dynamics model has been implemented into the stochastic IDEAL deposition code to compute particle deposition as well as vapour phase nicotine deposition in the different airway generations of the human lung.

The following parameters were simulated: evolution of the particle size distribution during breathing, particle concentration as a function of time, component mass fractions at different times during inhalation and exhalation, number and mass deposition fractions as functions of airway generations, and the distribution of nicotine mass deposited by the liquid and vapour phase.

Particle number concentration is reduced primarily by thermal coagulation, depending only slightly on particle composition. Simulations predicted number concentration losses in the human respiratory tract of roughly 95%, about 85% originating from coagulation. Furthermore, for e-cigarette aerosol, the mean hygroscopic growth of the particle size distribution correlates with the fraction of glycerol of the aerosol particles. Simulations showed that vapour phase deposition dominates the deposition mechanism of nicotine (post-evaporation from the aerosol), especially in the alveolar region. Finally, nicotine mass concentration within the particles decreased much more than suggested by evaporation and subsequent deposition. This is caused by dilution related to hygroscopic growth of the particles.

In conclusion, key physical events for both cigarette smoke and e-cigarette aerosol are early thermal coagulation in the mouth and hygroscopic growth in the airways. Deposition of nicotine is driven by evaporation from the droplet and vapour phase deposition, especially in the alveolar region. Chemical dose is driven by the very different chemistries of the respective aerosols.

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