Estimating the regional deposition of tobacco smoke in the human respiratory system

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Introduction

- Dose is a combination of concentration, location and duration. The fractional and regional deposition of cigarette smoke particles in the lungs has implications for the assessment of relative risk arising from smoking cigarettes or using alternative nicotine products.

Methods

- A study of volunteer smokers used real-time measurement of puffing, respiration and puffed/exhaled smoke particulate.
- Deposition of smoke particles from a range of commercial products (Ashley *et al* (2011), *Beitr.Tabakf.* **24**:277-288) with different ISO tar yields (1,4,7 mg), formats (King-size (KS), King Size Super Slim (KSSS) and filter types (carbon (C), non-carbon (NC)) under different smoking regimes was assessed.
- Nine volunteers smoked seven different products with their normal puffing regime at three different self-perceived but measured inhalation regimes: mouth hold only, shallow inhalation and normal inhalation.
- Measurements of puffing behavior, respiratory behavior, and physical and chemical measurements of puffed and exhaled smoke (solanesol content, tar, particle size) were recorded.
- Exposure data were generated by replicate smoking using measured puff parameters
- These data were then incorporated into a compartmental model for total and regional particle deposition in the human respiratory system.

Summary

- Results showed that product had a significant effect on puffing behavior but no significant effect on respiratory behavior. Puff volume was greater for ISO 1 mg products.
- Filter type and cigarette format had no significant effect on deposition fraction.
- ISO tar yield had a significant effect on total and regional deposition fraction. Deposition fraction decreased for ISO 1 mg products.
- There was evidence of coagulation and hygroscopic growth of smoke particles, with mouth hold time affecting coagulation, and with product affecting hygroscopic growth factor. Higher hygroscopic growth was associated with increasing pack tar.
- Predicted particle deposition rate correlated well to the square of particle diameter post-coagulation and hygroscopic growth, following Stokes' law for the deposition of spherical particles.

Measurement

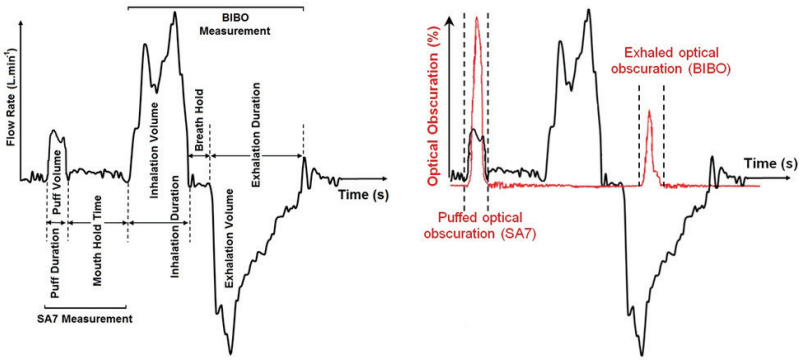
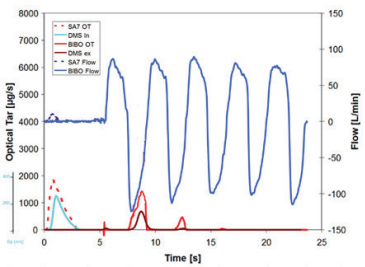


Figure 1 : Time-resolved puff and inhalation flow and volume (left) with puffed and exhaled optical obscuration (tar - OT) data (right). Puff data used for replicate smoking



Puff	Puff Vol [ml]	Puff Time [s]	OT [µg]	Aerosol Mass [µg]	No. Particles #	CMD [µm]
1	72.20	3.52	2114.08	804.03	1.16E+11	216.4
2	62.40	3.20	1853.09	602.06	8.93E+10	209.6
3	66.90	2.64	2137.56	1104.20	1.83E+11	202.7
4	67.30	2.84	2196.62	1465.02	2.25E+11	207.0
5	65.10	2.72	2108.94	1308.34	2.34E+11	195.0
6	63.10	2.44	1991.22	1304.17	2.73E+11	184.5

Respiratory Stats			Exhaled Smoke			
Mouth Hold [s]	Inhale Time [s]	Inhaled Vol [L]	OT [µg]	Aerosol Mass [µg]	No. Particles #	CMD [µm]
2.0	1.9	1.87	4614.15	417.90	2.46E+10	298.9
1.9	2.9	1.84	3094.96	318.20	2.25E+10	287.5
2.2	2.0	1.88	4442.02	480.02	2.96E+10	280.8
2.4	2.4	1.98	3212.25	410.08	3.01E+10	256.9
2.0	2.4	1.96	3754.96	426.59	2.82E+10	265.0
2.6	2.4	1.85	3728.83	431.69	3.12E+10	252.5

Figure 2 : Time-aligned data set ready for model input

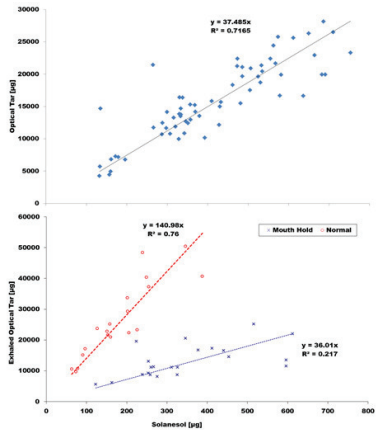


Figure 3 : Correlation steps : Solanesol ($C_{45}H_{74}O$) used as non-volatile tar marker to address influence of hygroscopic growth and droplet water accretion on 'exhaled optical tar'. Mouth hold data assumes no hygroscopic growth. Normal inhalation data gives subject and / or product specific hygroscopic growth factor. In practice, a product specific factor was derived

Modelling

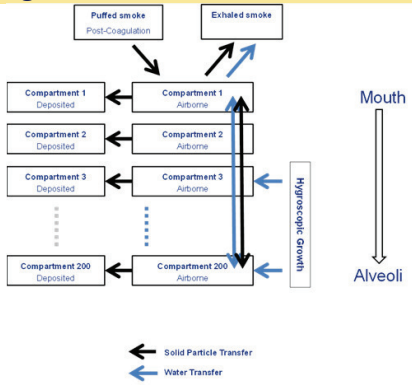


Figure 4 : Physiologically based compartment model of mass-based particle deposition, incorporating smoke dilution, diffusion and deposition and measured growth factors. In this case 200 compartments representing 0.04s steps were utilised. Normalisation between volunteers was based on measured vital capacity.

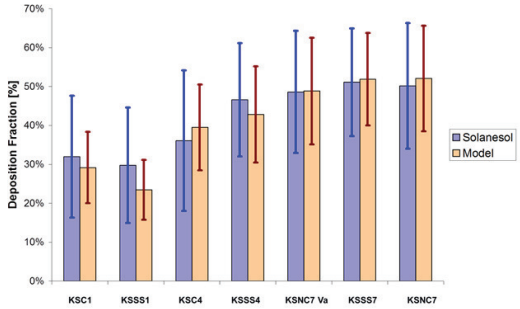


Figure 5 : Comparison of solanesol deposition fraction (direct measurement) versus model 'best-fit' particulate deposition.

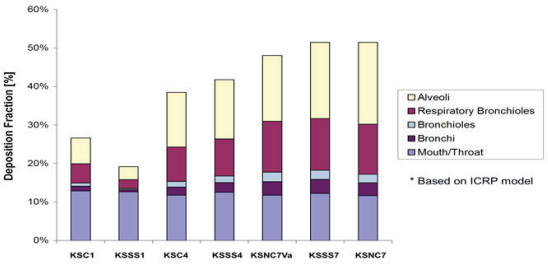


Figure 6 : Regional lung deposition split from model 'best-fit' particulate deposition.

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Nine volunteers smoked seven different products with their normal puffing regime at three different self-perceived but measured inhalation regimes: mouth hold only, shallow inhalation and normal inhalation. Measurements of puffing behavior, respiratory behavior, and physical and chemical measurements of puffed and exhaled smoke (solanesol content, tar, particle size) were recorded. Results showed that product type had a significant effect on puffing behavior but did not have a significant effect on respiratory behavior. ISO tar yield also had a significant effect on deposition fraction, potentially due to changes occurring to the particles post mouth hold. There was evidence of coagulation and hygroscopic growth of smoke particles, with mouth hold time having an effect on coagulation, and with product having an effect on hygroscopic growth factor. It is hypothesised that the hygroscopic growth of the smoke particles has a major effect on the deposition rate of the particles in the lungs.

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