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Size-Resolved Respiratory Tract Deposition of Ultrafine Hydrophobic and Hygroscopic Particles during Rest and Exercise Measured on 30 Human Subjects

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INTRODUCTION
Several studies, both epidemiological and toxicological, indicate that ultrafine particles are more likely to cause adverse responses on human health than the same mass of larger particles (e.g. Ibald-Mulli et al. 2002; Oberdorster et al. 1995; Peters et al. 1997). These studies suggest that not only the mass, but also the number or surface area of the particles may play an important role. Therefore the inhaled dose of particles (mass, surface and number) is crucial to determine, but so far it has only been measured to a limited degree and almost exclusively for monodisperse hydrophobic particles in laboratories with the test persons breathing in a fixed controlled manner.

The aim of this work is to determine respiratory tract deposition of polydisperse hydrophobic and hygroscopic particles during rest and exercise with a newly developed set-up (Löndahl et al., 2006). Because of the high relative humidity (RH) in the respiratory tract (up to 99.5%) hygroscopic particles grow and deposit differently from hydrophobic particles. Experimental data on this has, to the best of our knowledge, only been published to a very limited extent in international journals and only for seven subjects (Tu & Knutson 1984; Blanchard & Willeke 1984).

METHOD
An instrument has been developed to measure the respiratory tract deposition of polydisperse aerosols (RESPI, Löndahl et al. 2006). It was used to measure the size-resolved deposited fraction (DF) of particles in the size range 15-320 nm on 30 healthy, non-smoking subjects whereof 21 men and 9 women. Each subject completed four sessions, with a time of 21 minutes per session, using their own natural breathing pattern. Particle deposition was measured for one hydrophobic and one hygroscopic aerosol during both relaxed breathing (sitting) and light exercise on a bike, with a pulse of 65-75 % of maximum.

Two different nebulised aerosols were used: sodium chloride (NaCl, GMD 50-80 nm, $\sigma_{g}$ 1.9-2.0) and diethyl-hexyl-sebacate, (DEHS, GMD 100 nm, $\sigma_{g}$ 1.9). The produced aerosols were diluted in two separated experiments with filtered air in a 0.5 m$^3$ box to get a stable concentration around $10^5$ cm$^{-3}$ and a mass concentration below 0.5 mg/m$^3$.

RESULTS AND DISCUSSION
The mean size-dependent deposited fraction for all the subjects is shown in Figure 1. The mean tidal volume was $0.7 \pm 0.3$ L during rest and $2.2 \pm 0.6$ L during exercise with a breathing frequency of $11 \pm 2.4$ min$^{-1}$ and $16 \pm 4.2$ min$^{-1}$ respectively.

The particle dose increases considerably during exercise. The difference in DF was less than 0.08 between rest and exercise for all particle sizes of the same aerosol type. Because the DF remains almost unchanged the total dose of deposited particles becomes four times higher since the inhaled volumes are more than four times larger. Furthermore there are indications that a larger fraction of the deposited hydrophobic particles penetrates into the blood during exercise which would increase the dose in the vital organs further (e.g. Khazaeneinia et al. 2000).

No significant differences in deposition could be seen between men and women during relaxed breathing. During exercise the male test subjects had a DF approximately 0.03 higher than the female subjects.

![Figure 1. Mean values of respiratory tract size-dependent deposited fraction (DF) for 30 healthy non-smoking test subjects (21 male, 9 female) during rest and light exercise for one hygroscopic (NaCl) and one hydrophobic (DEHS) aerosol.](image-url)

Figure 1 illustrates the individual differences in DF of DEHS-oil during rest for 20 of the subjects. In general the subjects had the same relative DF in all
experiments, i.e. a subject with a low DF during one session also had a low DF during the other three sessions and vice versa.

Figure 2. The size-dependent deposited fraction of hydrophobic particles during rest for the first 20 subjects.

CONCLUSION

The study of the 30 subjects shows small variation in deposited fraction between rest and exercise. This, as well as the small difference in deposition between men and women, is in agreement with previous results (Daigle et al. 2003; Jaques & Kim 2000).

The large shift of the deposition curve due to particle hygroscopicity is expected considering the high RH (~99.5%) in the respiratory tract. Despite the fact that accumulation mode particles in ambient aerosols typically have diametric growth factors around 3–4 at 99.5% RH, very few studies have been made of the respiratory tract deposition of hygroscopic particles.

OUTLOOK

In the near future respiratory tract deposition of street canyon aerosols will be measured for the same group of subjects with the above described set-up. The measurements will be combined with techniques determining the hygroscopic properties of the investigated aerosols.

Keywords: Respiratory deposition, Particulate matter and Environmental health, Nanoparticle toxicology

REFERENCES


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