AEROSOL BOLUS DISPERSION AND RECOVERY IN A HUMAN AND DOG AIRWAY CAST

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INTRODUCTION

In recent years methods in lung diagnostics have been developed using the aerosol bolus inhalation technique (Heyder et al., 1988; Anderson et al., 1989; Schulz et al., 1995; Blanchard 1996). A bolus is a small volume of aerosol sandwiched in particle-free air and inhaled into different volumetric regions of the lung. During inhalation and exhalation the original small bolus is dispersed over a larger volume. This dispersion is caused by convective mixing in the airways and by intrinsic particle motion. Because particles in the size range between 0.2 and about 1 μm have low intrinsic motion, they can be used as tracers of the convective air transport in the lungs. The extent of broadening of the bolus measured in the exhaled air is a measure of the convective mixing during inhalation and exhalation, Blanchard (1996).

The bolus inhalation technique can also be used to deliver aerosol into specific volumetric regions of the lungs. If a bolus is inhaled near the end of an inhalation, the aerosol particles cannot penetrate deep into the lungs and should be delivered preferentially to the tracheobronchial airways. In order to determine where the particles from an inhaled bolus are located within the lungs at end inhalation, dispersion and recovery studies were made in a dog and a human airway cast.

MATERIAL AND METHODS

Aerosol

The monodisperse aerosol particles were produced by heterogeneous condensation of di-2-ethylhexyl sebacate (DEHS) vapour on NaCl nuclei. Two commercially available aerosol generators were used (MAGE, Lavoro E Ambiente, Bologna, Italy; TOPAS, Dresden, Germany). The terminal settling velocity ($v_s$) of the particles was measured with a convection-free sedimentation chamber. The aerodynamic particle diameters ($d_{ae}$) generated in this way ranged between 0.5 and 4 μm.

Airway cast

The lung casts were prepared from fresh lungs free of respiratory disease. A solid cast complete to the airways of 1 mm in diameter were made by filling the airways.
of the inflated lung with wax. Tissue was macerated from the solid wax cast. This cast was then coated with RTV silicone material. The hollow cast was obtained after melting wax out of the cast, Briant and Lippmann (1992).

The morphometry of the casts was measured and reported. The entire volume of the dog cast was about 160 cm³, the volume of the trachea was about 70 cm³. The human cast had a total volume of 125 cm³, with a trachea volume of 30 cm³. For some measurements a model of a human mouth cavity and oropharyngeal region was connected to the human airway cast. This model had an additional volume of 54 cm³.

**Aerosol administration**

The cast was ventilated by a piston pump while mounted within a ventilation chamber (Fig. 1). Part of the trachea was outside of the chamber and was connected to the mouthpiece of an inhalation device. With the inhalation device the aerosol concentration could be detected during inhalation and exhalation by laser photometry. The valve system of the device allowed small volumes of aerosol to be injected into the particle free inhalation air. The penetration of each bolus into the cast could be controlled by injecting the aerosol into various predetermined volumes during the clean air inhalation. At the end of any inhalation, periods of breathholding (tᵦ) could be chosen.

During the experiments, the relative aerosol number concentration (c) measured with the photometer as function of the inhaled and exhaled volume (V) were recorded and stored as c (V), (Scheuch et al., 1992). The influence of bolus penetration, ventilated flow rates, particle size, breathholding periods and mouth cavity were measured, (Scheuch et al., 1995). In this paper a comparison between both casts is given and the influence of an additional oropharyngeal region is demonstrated.
RESULTS

Figure 2 shows the particle recovery after bolus ventilation in different volumetric regions of the casts with particles of $d_{ac} = 0.6-0.9$ μm. Flow rate was chosen to be 250 ml s$^{-1}$. Both casts were adapted to the inhalation device with the same tube (10 cm long, inner diameter 1.2 cm). While the recovery from the human cast was 100% for volumetric penetration (VP) < 50 ml, particles from the dog cast were lost earlier (VP = 35 ml). Fewer particles were lost from the dog cast between 70 and 140 ml.

The results for dispersion measurements were identical in both casts for VP < 70 ml. For VP > 70 ml the dispersion in the dog cast was significantly higher (Fig. 3). The connection between the cast and the inhalation device had a significant influence both on aerosol recovery and dispersion. In Figs 4 and 5 the recovery and dispersion after bolus injection into the human cast are given, respectively. Results of measurements are compared between connection with a mouth cavity and an oropharyngeal (MO) model and the short tubing described above. It can be seen that the MO model leads to a distinct increase in dispersion. The recovery measurement between VP = 50 and 150 yielded a higher particle recovery from the cast with the oropharyngeal model than with the human cast alone. In Fig. 5 the results of dispersion measurements of eight healthy human volunteers are also given as a comparison.

DISCUSSION

Particle losses during the ventilation cycle are caused by losses from particles into
Fig. 3. Bolus dispersion (SD) as function of the volumetric penetration of the bolus. Comparison between human cast and dog cast.

Fig. 4. Aerosol recovery as function of the volumetric penetration of the bolus. Comparison between human cast connected to the mouth piece of the inhalation device (intubated) and a measurements using an additional model for the oropharynx.
the ventilation chamber and by deposition onto the walls of airways. By using particles with aerodynamic diameters between 0.6 and 0.9 μm losses by deposition are small compared to the losses into the ventilation chamber. Particles penetrating through the open ended 1 mm airways of casts reached the 5 l ventilation chamber. Only a minor fraction (<3%) can find the way back into the cast and will be detected with the photometer during the exhalation cycle. A recovery of 100% of the aerosol shows that no particles are deposited or reached the ventilation chamber. They are recovered from the airways of the cast. From Fig. 2 it can be seen that up to a bolus penetration volume of VP = 65 ml less than 5% of the aerosol left the cast and, therefore, could reach airways <1 mm in diameter. For the human cast less than 2% were lost for VP < 50 ml. Because of the smaller total volume of the human cast more particles were lost at VP = 50–150 ml compared to the dog cast. An additional oropharyngeal region adapted to the human cast lead to smaller losses into the ventilation chamber. Up to a bolus penetration volume of 120 ml the losses out of the human cast airways and by deposition were smaller than 5%.

From Figs 2 and 3 it can be seen that the dispersion and recovery from human and dog cast itself showed similar results for shallow boluses. The dispersion in the dog airways are slightly higher for VP between 70 and 150 ml. This may be caused by the different branching pattern of the human and dog cast airways. The human airways have a more dichotomous branching pattern.

An additional oropharyngeal model between the trachea of the human cast and the inhalation device lead to much higher dispersion. This may be caused by mixing
in low ventilated regions of the oropharynx (Scheuch et al., 1995). Cast measurements and measurements in healthy human volunteers and on living dogs (Scheuch et al., 1995) using the same inhalation device resulted in very similar dispersion data (Fig. 5), suggesting that the cast serve as a good model of in vivo behaviour of aerosol boluses.

CONCLUSION

These investigations showed that the bolus inhalation technique can be used as a tool to deposit aerosol particles in conducting airways. By inhaling boluses in volumetric regions of less than 60 ml (80 ml in human) over 95% of the aerosol will be located in airways of more than 1 mm in diameter. The dispersion measured in shallow volumetric lung depths are mainly caused by dispersion mechanisms in the oropharyngeal region. Dispersion in human airways is slightly smaller than in dog airways.

REFERENCES


