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Aerodynamic properties of biohazardous aerosols in hospitals

Key Messages

1. Knowledge of the aerodynamic properties of biohazardous aerosols is important for infection control.
2. The aerosol dynamics involved in coughing and cough-related phenomena are complicated, poorly understood, and require further study.
3. Mature atmospheric aerosol measurement technologies can be used to study aerosols in hospital or clinical environments. This greatly enhances the understanding of the transmission of infectious diseases.

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Introduction

The 2003 severe acute respiratory syndrome (SARS) outbreak instigated discussion in Hong Kong on the mechanisms governing the transmission of respiratory diseases through the atmosphere, and the role of disease-containing droplets or aerosols in that process. The continuing occurrence of avian influenza H5N1 in Southeast Asia has further emphasised the need to better understand aerosol transmission routes. These emerging infectious diseases are caused by tiny pathogens measured on the nanometer scale. Once airborne, they behave like ultrafine particles and can be transported long distances.

Little has been written on biohazardous aerosols generated in a clinical environment. Biohazardous aerosols are routinely generated in hospitals by processes such as breathing, coughing, sneezing, intubation, non-invasive ventilation, delivery of medication by nebulisation, surgery, feeding of patients, and sanitisation of toilets. It is therefore important to understand the behaviour and dynamic properties of these bioaerosols. Appropriate source abatement technology, ventilation strategies, and personal protection schemes can then be developed and adopted for effective curtailment of their dispersal and for isolation of these biohazardous aerosols to reduce the risk of cross-infection in the clinical environment.

Coughing is a symptom of respiratory diseases including SARS, flu, and tuberculosis. Coughing produces aerosols that are made up of fluids from the airway which may contain micro-organisms. Traditionally, cough aerosols have been loosely referred to as 'droplets' or 'airborne aerosols'. The term 'droplets' refers to larger particles that will settle within a short distance, say 1 m, from the source, while 'airborne aerosols' suggests longer transport distances. The dynamic properties and behaviour of particles in the atmosphere have been much studied in recent years by atmospheric scientists.[1] Particles, technically known as aerosols, as large as 100 mm (coarse particles) and smaller than 0.3 nm (ultrafine particles) in aerodynamic diameter are routinely detected in the atmosphere. This size range is wider than the range seen in cough aerosols, based on what is described in the literature.[2,3] From an aerodynamic point of view, all cough aerosols are airborne. This challenges the conventional wisdom on the aerodynamic behaviour of cough aerosols and, therefore, the transmission of infectious diseases through the atmosphere. This project used air pollution research technology to investigate the aerodynamic properties and behaviour of cough aerosols and their significance in disease transmission.

Aims and objectives

This study aimed (1) to design and develop sampling systems and protocols for the determination of the source profiles and the dispersion characteristics of aerosols generated by high-risk aerosol-generating procedures; (2) to determine the total mass loading, particle size distribution, velocity and trajectory of the aerosols generated by coughing and the high-risk aerosol-generating procedures.

Methods

This study was conducted from December 2004 to June 2006.

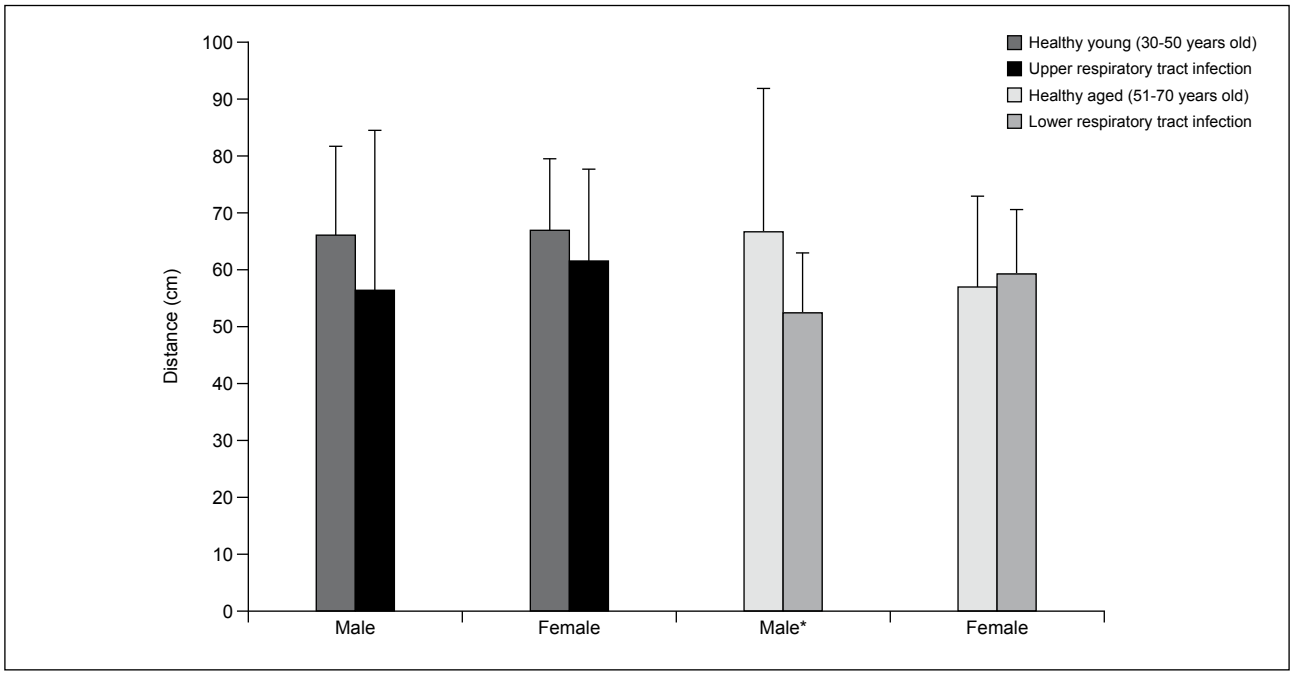

Fig. Maximum longitudinal dispersion distances (mean ± standard deviation) of the study groups
* P<0.01

Nebuliser-generated aerosols

Aerosols were generated with a clinical jet nebuliser. The dispersion of the nebulised aerosols were studied using (1) a mannequin with no mask attached, (2) a mannequin wearing a mask, (3) a male and a female human subject (one each) wearing a mask, and (4) a mannequin wearing an in-line high-flow oxygen mask. The Aerodynamic Particle Sizer Spectrometer (APS; TSI Inc, Shoreview, MN, US) was used to measure the aerodynamic size of the aerosols.

Cough aerosols

Eighty healthy subjects, 51 patients with upper respiratory tract infections (URTI), and 56 patients with lower respiratory tract infections (LRTI) participated in this study. The total gravimetric mass, number concentration, and size distribution of the aerosols were measured.

Aerosol trajectories by imaging technique

A custom-designed, low-cost digital imaging system was developed and built for this project to study the cough aerosol plume trajectories.

Results

Particle number concentration, and size distribution profiles along the main dispersion axis followed an exponential decay model. An exception to this was the very high flow rates from the high-flow oxygen mask, where the dispersion was linear. The particle size distribution exhibited uni-modal characteristics except when it was close (10 cm) to the mouthpiece of the nebuliser, dispersing without a mask. This suggests that the evaporative loss of the water in nebulised aerosols is important during transport and that this process is very fast.[4]

Over 95% of the cough areosols discharged by the healthy subjects were smaller than 1 μm in aerodynamic diameter. The size of the cough aerosols produced by all groups followed this order: LRTI > URTI > healthy subjects. The unit mass concentrations showed a reverse pattern, ie healthy subjects > URTI > LRTI. The patient groups also had higher aerosol number concentrations than the healthy group but there was no discernible trend for the total mass concentration.

The maximum cough velocities and the duration of the coughs measured agreed well with reported values in the literature. The maximum plume velocity of the healthy and URTI subjects was 2 m/s. The lengths of coughs of the healthy, URTI, and LRTI subjects were approximately 1 s, 1.2 s, and 2.5 s, respectively.

The Figure shows the maximum longitudinal dispersion distance (d_{max}) for different subjects. There was no significant gender difference between all the groups. Only male subjects with LRTI produced cough aerosols with significantly shorter travel distances than the healthy male subjects. From these results, it appears that a nominal distance of ~60 cm is needed for the cough plume to be 'completely' diluted.

The modal particle sizes at different horizontal distances from the nebuliser are shown in the Table. The particle size distributions were uni-modal except at the closest distance

Table. Summary of the mode sizes of the dispersed aerosols

Distance (cm)	Mode size of aerosols (μm)
10	1.07, 3.79
20	0.78
30	0.60
50	0.58
100	0.62
150	0.68

from the nebuliser (10 cm) where it was bi-modal. At a distance less than 10 cm from the nebuliser, the aerosol concentration is too high and overloads the APS. The mode shifted from 1.07 and 3.79 μm at 10 cm to 0.78 μm at 20 cm and it became relatively steady at approximately 0.60 μm from 30 cm onward. This suggests that the aerosols experienced a sharp reduction in size once emitted into the air. Since the majority (over 95%) of the dispersed aerosols were smaller than 10 μm, deposition loss due to gravity would be minimal. The reduction in size was probably due to the evaporative loss of water.

Discussion

Aersosols generated from nebulisers or coughs evaporate rapidly in room environments. This reduces their size and increases their ability to remain in the air for transport. The exponential model generated by this study allowed estimation of the distance required for the dispersion to dilute the aerosols to background concentration level. For the controlled quiescent indoor environment used in this study, the worst case scenario–estimated distance was 6 m. This is important information for the control of infectious disease transmission.

To the best of our knowledge, this study provides the first set of aerodynamic diameter and mass particle size distribution data about cough aerosols from healthy subjects and patients with upper and lower respiratory infections. Patients with respiratory symptoms produced larger aerosols than healthy people, without increasing the cough mass. The size distribution of the number and mass of the cough aerosols provides a platform for assessing the pathogen loading if source information is available. These data are needed to better understand the transport path and mechanism of cough aerosols.

The custom-designed, low-cost digital imaging system developed and built for this project was effective for measuring the cough aerosol plume trajectories. The maximum cough velocities and the duration of the coughs thus measured agreed well with reported values in the literature. The results suggest that different control strategies may be needed for different groups in clinical environments because of the variation in cough characteristics.

Conclusions

The everyday common cough experienced by all human beings is a very complicated process involving physiological, biochemical, and aerodynamic aspects. These processes determine the transmission of virus which, in turn, affects the risk to others of contracting an infectious respiratory disease such as SARS, avian influenza, or tuberculosis. This work represents the first attempt to apply technology normally used in air pollution research to investigate infectious disease transmission. The project also underlines the importance of interdisciplinary collaboration for solving complicated and difficult problems. It has been demonstrated that the measurement technology used by atmospheric scientists for decades to study the dynamic behaviour of atmospheric aerosols can be successfully transplanted to a study of the bioaerosols generated in clinical and hospital environments. This can greatly enhance the understanding of the transmission of infectious respiratory diseases. The uneven dispersal from the two nozzles of the face mask needs to be resolved. The anomaly seen in the high-oxygen flow mask, involving a change in the flow model, has possible implications for aerosol transport and needs further study. Although the low-cost custom-built imaging system performed adequately in this study, a laser-based lighting system and professional quality high-speed digital video camera would improve the imaging and imaging analysis. This non-invasive imaging system can be applied to other medical procedures.

Acknowledgement

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