Experimental study on aerosol inhalation of the human upper airway

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Abstract: The study of aerosol deposition in the human upper respiratory tract is of great significance for understanding the impact of toxic aerosols on human health and improving the therapeutic effect of drug aerosol inhalation. 3D printing technology was used in the experimental model of the human upper airway. A laser particle size analyzer was used to study the deposition of aerosol particles with a particle size of 1-20 μm inhaled in the upper respiratory tract of the human body, and the particle deposition rules of the aerosol particles in the upper respiratory tract were analyzed. The experimental results show that aerosol particles remain more in the pharynx, larynx and position. For particles with a particle size of 1-5 μm, more deposition will occur in the trachea, and for particles with a particle size of 10-20 μm, most of them will be deposited in the mouth.

1. Introduction

In recent years, respiratory diseases caused by aerosols such as the new coronavirus, influenza A virus and severe smog through the upper respiratory tract of the human body have attracted more and more attention. Studying the deposition rules of aerosol particles in the upper respiratory tract of the human body is of great significance for clarifying the impact of toxic aerosols on human health and improving the effect of releasing drug aerosols in the treatment of various respiratory diseases of the human body[1-5]. At present, most studies on particle deposition in the human upper respiratory tract are based on numerical simulation methods. For example, Storey-Bishoff [6]simulated the movement of particles with aerodynamic diameters ranging from 0.8 to 5.3 μm in the upper respiratory tract, and found that the deposition rate Depends on Reynolds number, Stokes number and airway size. Cui, X.G et al.[7]used the open source software OpenFOAM to simulate the two-phase flow by using the one-way and two-way coupling between the gas phase and the particle phase, and studied the deposition and diffusion of monodisperse and polydisperse particles in the upper respiratory tract, respectively. F.Huang et al.[8]studied the deposition mechanism of three different mouth-throat models (USP M-T, Idealized M-T, Realistic M-T), considering the effects of different airflow velocities and particle sizes on particle deposition, and using the SST model to solve the problem Flow field equations, using the discrete phase method (DPM) to track monodisperse particles in the particle size range of 1–30 μm. The results show that the change of the geometric model has a great influence on the spatial deposition distribution of particles. Compared with the USP M-T model, the Idealized M-T model and the Realistic M-T model are more in line with the real situation of the respiratory tract.

In this study, referring to the geometric structure of the idealized mouth-throat model developed by ARLA9(Aerosol Research Laboratory of Albeeta), a complete and real human upper airway normative model was established. The deposition of aerosol particles in the human upper respiratory tract was studied. To study the deposition of aerosol particles in various parts of the upper respiratory tract. e advised that papers in a technically unsuitable form will be returned for retyping. After returned the manuscript must be appropriately modified.

2. Experimental equipment and methods

Fig.1 is a schematic diagram of the upper respiratory tract deposition experiment. The experimental system mainly includes a human upper respiratory tract model, an atomization device, an aerosol particle measurement system, and a terminal control system.

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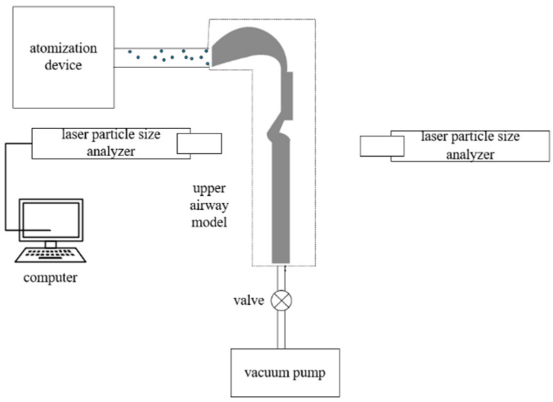

Fig.1 Experimental schematic

2.1 The human upper airway model

Referring to the geometric structure of the idealized mouth-throat model developed by ARLA[9] (Aerosol Research Laboratory of Albeeta), the upper airway model is composed of the oral cavity, pharynx, larynx, and trachea. The oral cavity is smoothly connected, the average cross-sectional area of the pharynx is 3.05cm^2, and the larynx is in the shape of an elliptical cylinder. The glottis is located at the protrusion of the larynx. of cylindrical shape. Finally, the model used in the experiment was completed by 3D printing technology, as shown in Fig.2

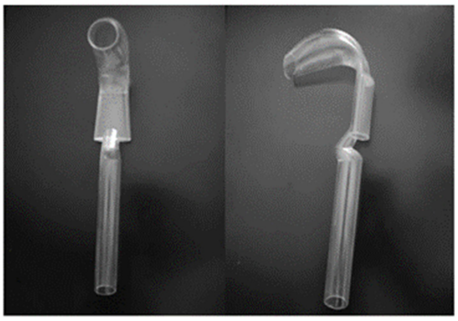

Fig.2 Experimental model of aerosol deposition in human upper airway

2.2 Atomization deviceirst

In order to simulate the deposition of particles in the upper respiratory tract of the human body during real nebulization inhalation, the ultrasonic nebulizer produced by Folee was used in the experiment. The principle of the ultrasonic nebulizer is to use the piezoelectric transducer in the high-frequency alternating electric field to convert the electrical signal into a mechanical vibration with periodic changes, so that the molecules of the liquid medicine vibrate, and as a result, the liquid interface is broken, thereby To achieve atomization, it can produce polydisperse droplets with a particle size of 1-20 μm.

2.3 Measurement system

Commonly used methods for measuring droplet size are:mechanical measurement,electronic measureme-nt, and optical measurement[10]. In this paper, the Malvern method in the optical measurement method is used to obtain the microscopic indicators of the spray characteristics. Light scatters because it encounters tiny particles along its path. Electromagnetic wave theory accurately describes the scattering phenomenon of light: as the particle size decreases, the scattering angle will become larger. Therefore, to calculate the size of particles, it is only necessary to detect the distribution of scattered light, which is the principle basis for the measurement of particle distribution by laser particle size analyzers. The schematic diagram of its principle is shown in Fig.3. In this experiment, OMEC DP-02 laser particle size analyzer was used to measure the characteristics of fog droplets. The instrument is composed of a collimated laser generator, a signal acquisition device and a data processing system. The collimated laser generating device is composed of a laser tube, a beam expander system, a collimating lens, and a Fourier lens; the signal acquisition device is mainly composed of a main detector, an auxiliary detector, a regulated power supply, and a data acquisition circuit; the data processing system is composed of a computer and program compositionhis section must be in two columns.

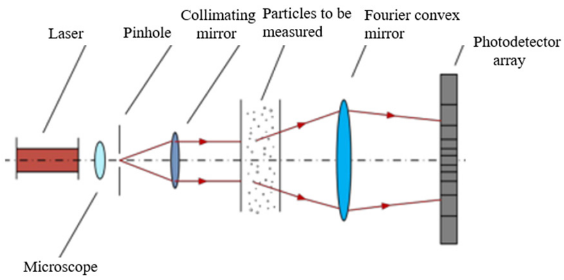

Fig.3 Schematic diagram of the working principle of the laser particle size analyzer

2.4 Experimental procedurehe

(1) Adjust the laser particle size analyzer so that it is adjusted to a horizontal state to ensure that the laser irradiates the upper respiratory tract experimental model horizontally.

(2) Start the ultrasonic atomizer, use water as the medium to materialize it, and connect the outlet of the atomizer to the oral cavity of the upper respiratory tract of the human body.

(3) Turn on the vacuum pump, use the suction effect of the vacuum pump to simulate the human inhalation process, and control the suction time and suction state opening and closing through the valve.

(4) Control through the computer terminal, analyze and calculate the measurement results.

3. Experiment results and analysis

Before the test, the particle size of the droplets produced by the ultrasonic atomizer was measured. The measurement results are shown in Fig.4. It can be seen from the figure that the atomizer can produce droplets with a particle size of 1-20 μm , which meets the experimental requirements. However, the particle size distribution of the polydisperse droplets produced by it is uneven, and the droplets with a particle size of 5-10 μm account for a relatively large proportion, which will cause large errors in the experimental results.

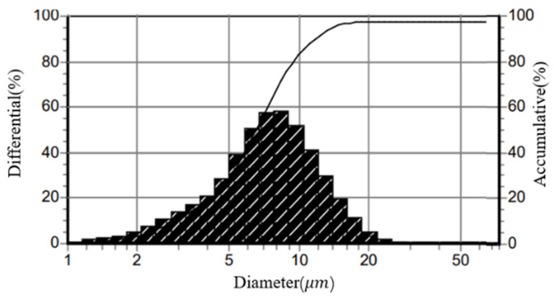

Fig.4 Particle size distribution diagram of atomizer

By adjusting the position of the upper respiratory tract experimental model, the laser distribution of the laser particle size analyzer is irradiated along the characteristic cross-section shown in Fig.5. O1, O2, O3, and O4 are selected for the four parts of the mouth, pharynx, larynx, and trachea, respectively. Characteristic cross-sections to observe particle deposition at different locations in the upper airway and measurements of particles at the outlet.

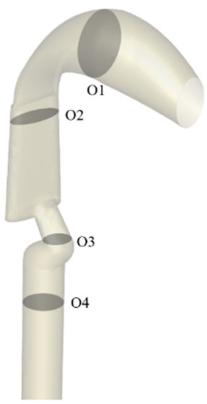

Fig.5 Feature cross section

Fig.6 shows the measurement results at O1, representing the cumulative distribution of particles with different particle sizes here. It can be seen that the distribution of particles with a particle size of 5-10 μm accounted for the largest proportion, and the distribution of particles with a particle size of 1-3 μm accounted for the largest proportion. smaller. Generally speaking, due to inertia, particles with larger particle sizes will deviate from the flow line of the fluid, impact the curved airway wall in the oral cavity, and then achieve deposition, so particles with larger particle sizes are more deposited in the mouth.

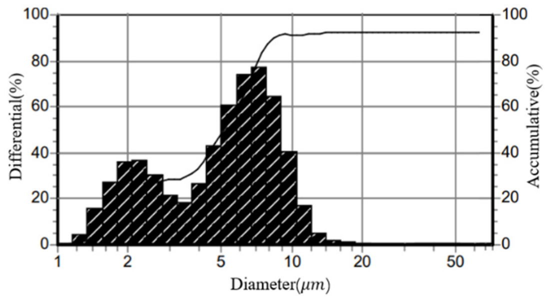

Fig.6 Distribution of different particle sizes at O1

Fig.7 shows the measurement results at O2. The characteristic cross-section of O2 is located in the pharynx. The contraction of the pharynx structure leads to more particle deposition here, which is not much different from that at O1. The distribution of particles with a particle size of 5-10 μm is more. The particle size distribution here is relatively uniform. Due to the deposition of larger particle size particles at the mouth, the proportion of particles with a particle size greater than 5 μm decreases. The small particle size at the O2 place did not decrease significantly.

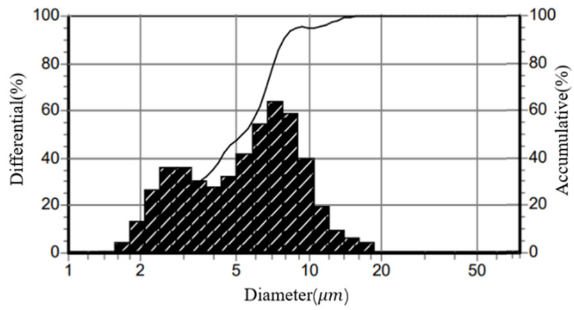

Fig.7 Different particle size distribution at O2

Fig.8 shows the measurement results at O3. The characteristic cross-section of O3 is located at the glottis of the larynx, which is a narrow area, resulting in the deposition of particles with smaller particle sizes. It can be seen from the figure that there are particles with a particle size of less than 5 μm Distribution, but the proportion of distribution is not high, less than 20% of the total. Particles larger than 15 μm are almost zero here, where the particle size distribution is broad.

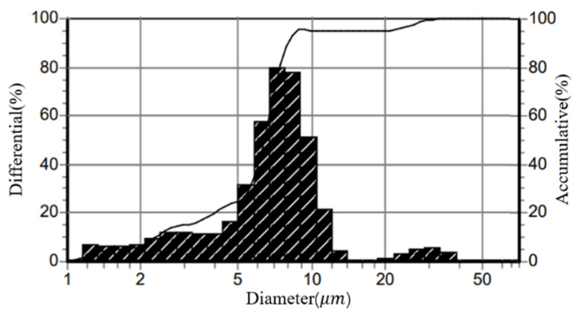

Fig.8 Different particle size distribution at O3

Fig.9 shows the measurement results at O4. The characteristic cross section of O4 is located at the trachea. The particles flow through the mouth to the pharynx, throat, and finally reach the trachea. It can be seen that the distribution of particles with a particle size of less than 5 μm is relatively large at O4 Large, this is due to the deposition of larger particles before reaching the trachea.

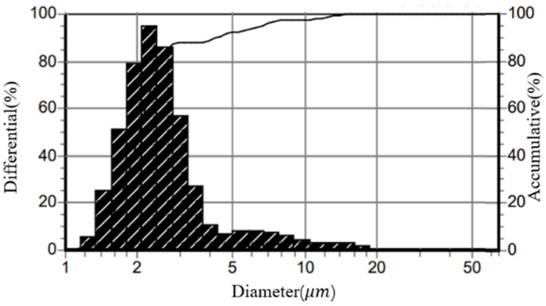

Fig.9 Different particle size distribution at O4

Fig.10 shows the measurement results at the outlet of the airway. It can be seen that the proportion of particles with a particle size of 1-2 μm is the highest, indicating that aerosol particles pass through the mouth, throat, and finally enter the trachea. The particles with a particle size of 1-2 μm particles are more likely to enter the bronchi and lungs. Particles with a particle size >5 μm are basically deposited in the upper respiratory tract, and only a few can enter the bronchi.

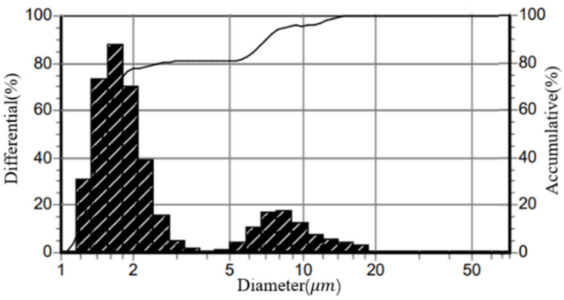

Fig.10 Different particle size distribution at the outlet of the airway

4. Conclusions

Experimental research on the inhalation process of aerosol particles with a particle size of 1-20 μm, analyzed the deposition characteristics of aerosol particles in different parts of the upper respiratory tract, and analyzed the mouth, pharynx, and The proportion of aerosol particle deposition in the larynx and trachea, the following main conclusions were drawn:

(1)Aerosol particles with a particle size of 10-20 μm are easier to deposit in the mouth and pharynx, and it is difficult to reach the trachea, and the deposition in the mouth accounts for the largest proportion.

(2)Aerosol particles with a particle size of less than 5 μm account for a large proportion of deposition in the trachea, indicating that it is easier to enter the lungs and achieve "target" drug delivery.e hope you find the information in this template useful in the preparation of your submission.

Acknowledgements

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