

# Droplet generation due to two health care procedures

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**Abstract:** Preliminary experiments are carried out to characterize the droplets generated in two aerosol-generating health care procedures, i. e. taking nasopharyngeal aspirates (NPA) and nebulizer therapy. Glass slides and water-sensitive paper (WSP) are used to collect large droplets when taking NPA. Droplet stain-marks on glass slides are counted under a microscope, and then a size analysis is performed. During nebulizer therapy dust monitors are used to detect small droplets and droplet nuclei at different positions around the nebulizer and in the room. From the preliminary results it is found that taking NPA can stimulate coughing and generate large droplets. Nebulizers can generate more than tens of millions fine droplets ranging from 0.3 to 20  $\mu\text{m}$  per minute, a large volume of which can escape from the holes on the nebulizer's facemask and disperse in the whole room. Droplets coagulate on the inner surface of the mask and the volunteer's face, suggesting a great possibility of drug solution contamination by patients' secretion during nebulizer therapy.

**Key words:** droplet; taking nasopharyngeal aspirates (NPA); nebulizer therapy; infection transmission

Since the 2003 severe acute respiratory syndrome (SARS) outbreaks, there has been an increased interest in the transmission of infectious pathogens by large and fine respiratory droplets. In addition to the exposure to the respiratory droplets from the patients' expiratory activities, the exposure to aerosol-generating health care procedures will also cause infection spread<sup>[1-5]</sup>. Diagnostic and therapeutic procedures inside the hospitals, such as sputum induction, bronchoscopy, endotracheal intubation, airway suction and aerosolized medication treatment, are potential aerosol-generating procedures, and are recognized as high-risk health care procedures<sup>[6]</sup>. It was reported that a SARS outbreak in a public hospital in Hong Kong could have been magnified by the use of a nebulized bronchodilator, causing the atomization of the infected secretions<sup>[7-8]</sup>.

Currently, there is, however, no measured data on the number and sizes of released droplets during any of these procedures. Such data are needed to further investigate the predominant infection routes, as well as infection control methods such as selecting adequate personal protection measures. The studies reported in this paper are thus undertaken to determine the number and sizes of droplets emitted by two aerosol-generating procedures in hospitals, i. e. taking

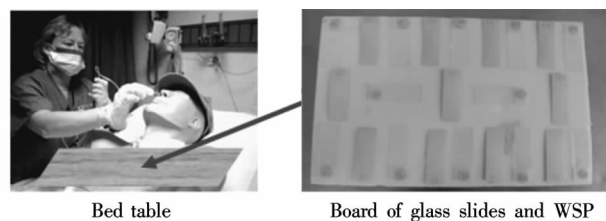
nasopharyngeal aspirates (NPA) and the use of nebulizers. The two procedures are chosen due to their different mechanisms of droplet release into the environment. Since NPA are much more sensitive to RT-PCR testing than other upper respiratory tract specimens, sampling by NPA is commonly used, while it is invasive and painful, and may induce coughing. There are also many measured data of droplet generation by various types of nebulizers<sup>[9-11]</sup> for pharmaceutical purposes. The physical mechanism of droplet generation by the commonly used jet nebulizers are explained by Finlay<sup>[12]</sup>. However, our interests here are the escaped droplets into the environment with the use of nebulizers, not the inhaled droplets.

## 1 Methodologies

### 1.1 Taking nasopharyngeal aspirates

Experiments are conducted in a general ward at the Queen Mary Hospital in Hong Kong where taking patients' photos is not permitted. So the schematic diagram of the experimental setup (see Fig. 1) is drawn based on the left picture which is obtained from the Johns Hopkins Medicine's website<sup>[13]</sup>. Twelve pieces of clean glass slides and 11 pieces of water-sensitive paper (WSP) labeled and attached to a plastic board (40 cm in length and 25 cm in width) are used to collect the droplets produced during the procedure, which is put on the patient's bed table. The bed table is moved as close as possible to the patient, just below the patient's mouth (see Fig. 1), but not disturbing the health care workers' operation. When large droplets are generated during the procedure of taking NPA, they may fall down and be deposited on the board. We also use a dust monitor (Grimm 1.108, Germany), which can provide real-time size measurements of aerosols from 0.3 to 20  $\mu\text{m}$ , to detect fine droplets, but the concentration results do not show that there are aerosols generated. This may be because too few droplets are generated or these measurements are performed in an open area; therefore, the aerosol concentration is too low to be detected. So, in this study we only focus on the droplets detected on the glass slides and the WSP.

After the experiments, the droplet stain-marks on the glass



**Fig. 1** Schematic diagram of experimental setup during taking NPA

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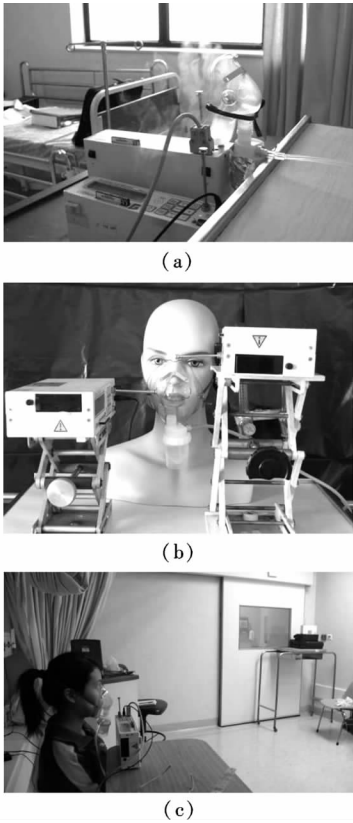
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slides are counted under a microscope<sup>[14]</sup>. The slides are completely scanned under a microscope (Leica DM1000, Leica Microsystems, Germany). We distinguish the droplet stain-marks by morphology. Usually, a “ring” can be observed surrounding the dried residue of a droplet. Every droplet stain-mark is photographed with a high resolution CCD camera (Leica DFC320, Leica Microsystems, Germany) connected to the microscope. The sizes of these stain marks are analyzed using an image processing software developed in our laboratory. If water droplets attach to the WSP strips, their color will turn to dark blue from the original yellow. Then the blue spots can be visually distinguished and then roughly counted.

1.2 Nebulizer therapy

Experiments are carried out in an empty isolation room in the Queen Mary Hospital. The jet nebulizer (see Fig. 2(a)) is exactly the same as the type used during the SARS outbreak in Hong Kong<sup>[7-8]</sup>, which is based on the Venturi principle and driven by oxygen. Two 16-channel dust monitors (Grimm 1.108, Germany) are used to measure the number and sizes of droplets from 0.3 to 20 μm. The sampling flow rate is 1.2 L/min and the reproducibility is ±2%. Measurements are conducted at different positions around the nebulizer, when only a nebulizer is used and when a facemask is worn by the manikins or by real persons (see Fig. 2). For most of the experiments, the flow rate of oxygen is set at 5 L/min, which is a little smaller than the value of 6 L/min used in the reported SARS outbreak in Hong Kong<sup>[7-8]</sup>. Both



**Fig. 2** Photos of experimental setups during aerosol measurements of nebulizer therapy. (a)Nebulizer facemask; (b)Female manikin wearing a nebulizer facemask; (c)Female volunteer wearing a nebulizer facemask

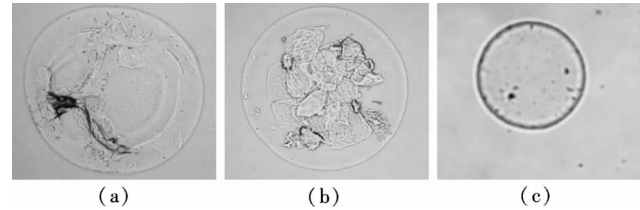
distilled water and 0.9% (weight in volume) saline solution are used as the simulated drug solution. During each day’s experiments, the background particle concentration inside the room is first measured. When saline water is used, as the droplet nuclei (dry residue of generated droplets) remain inside the room and change the background particle concentration, we also measure the background particle concentration.

2 Results and Discussion

2.1 Taking nasopharyngeal aspirates

Experiments are performed on four patients: 1) The first patient is a very old man and can barely speak. During taking NPA he groans loudly. 2) The second patient is also a very old man and can barely speak. He also groans loudly. Moreover, he coughs during the procedure. 3) The third male patient is about 45 years old and coughs frequently. He also coughs during the procedure. It is not the first time that this procedure has been performed on him. 4) The fourth one is about 25 years old. He coughs occasionally, but he does not cough during this procedure. This procedure is performed on him for the second time. He mentioned that it was very painful the first time during which he coughed and shed tears.

We wait to be informed when there are patients needing to have NPA taken. The same set of glass slides and WSP are used for the first and second patients as we do not have enough time to do preparation. Fig. 3 shows the microscopic pictures of stain marks of droplets emitted when taking NPA. The numbers of droplet stain-marks on the glass slides and the WSP obtained from four patients are shown in Tab. 1. The sizes of the droplets detected on the glass slides range from 15 to 236 μm. From Tab. 1 we can find that more droplets are obtained from the third patient than from other patients. When taking NPA, droplets may come from the patient’s cough, or from the procedure itself. The third patient has the symptom of frequent coughing, and he also coughs during this procedure. From these results it seems that the procedure of taking NPA itself does not generate many droplets. The patient’s cough may be the major cause of droplet generation. The cough may be due to the patient’s illness, or may have been stimulated by this procedure.



**Fig. 3** Microscopic pictures of stain marks of droplets generated during taking NPA

**Tab. 1** Numbers of droplets stain-marks on glass slides and WSP obtained during taking four patients’ NPA

Patient	Number of droplets detected	
	Glass slide	WSP
Patients 1 and 2	8	5
Patient 3	20	72
Patient 4	4	0

## 2.2 Nebulizer therapy

Particle concentrations are measured at different positions around the nebulizer. First, we use pure water as the drug solution. When a facemask is worn by a manikin (rather than a real person), after aerosol generation, a visible droplet cloud from the holes on the mask is observed moving downwards because of density. As this jet nebulizer can substantially decrease the reservoir solution temperature, the downward movement will be more obvious after a few minutes of aerosol generation. Some droplets can also reach a distance of 20 cm from the mask, but the amount is very small. At that distance the size distribution is very close to that of the background. If the mask does not fit the manikin's face as in the case of the female manikin, the droplet can not only come out from the two holes on the mask, but also from the gap between the mask and the manikin's nose. A visible droplet cloud ("smoke") is observed coming out from the upper part of the mask and a large amount of particles is detected by the dust monitor. When a real person wears the mask, the dispersion of the droplet cloud is different from that described above. The warm human plume and human breath influence its dispersion pattern, and make it unstable. The "smoke" can go upwards. To reduce the effect of the reservoir solution's cooling, after each measurement we change the solution. The visible horizontal distance and vertical distance that the droplet cloud can reach are both greater than 20 cm.

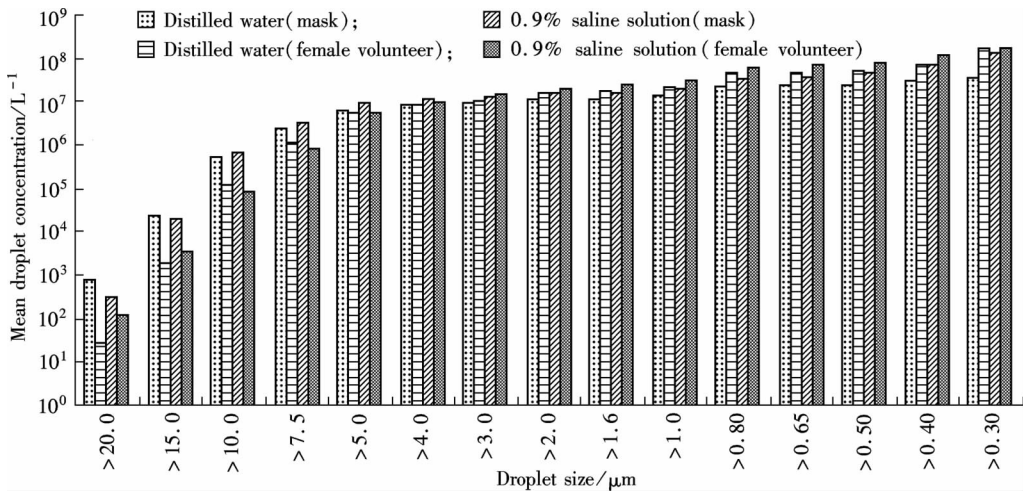


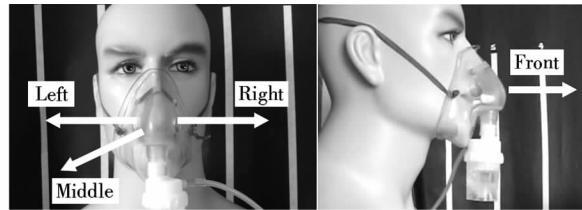
Fig. 4 Droplet concentrations in different size ranges generated by the jet nebulizer

During actual nebulizer therapy, a drug is usually added to the solution. The generated drug droplets cannot totally disappear (evaporate), and will form droplet nuclei suspended in the indoor air. Once the drug solution is contaminated by the patient's secretion, the nebulizer can aerosolize the contaminated drug solution into a large number of droplets, which will disperse in the air. Not only can these droplets transmit infectious diseases, but also the residues of droplets after evaporation (droplet nuclei) may contain pathogens and transmit infections. In our experiments, a 0.9% saline solution is used to simulate the drug solution. The particle concentrations at different positions inside this room are measured. In Fig. 6 particle concentrations and percentages in different particle size ranges are plotted based on the experiments of a female volunteer wearing a facemask. Sam-

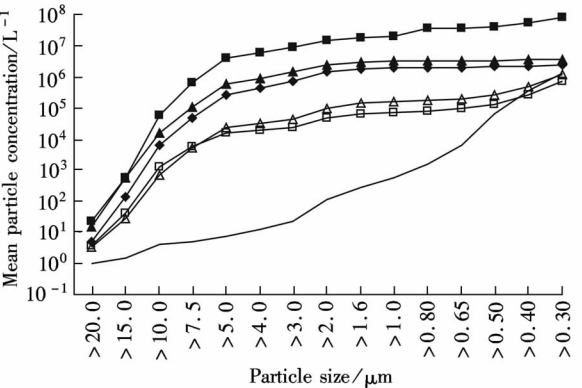
pling positions are indicated in Fig. 6(a). The background particle concentration before each measurement is found to be different due to droplet nuclei. To compare the results, we subtract the background particle concentrations from the measured values to represent the net particle concentration values at different positions, which are shown in Fig. 6(b). For some large particle sizes, negative values are obtained, which are not shown in Fig. 6.

Fig. 4 shows the droplet concentrations in different size ranges. We can see that more than tens of millions of droplets larger than 0.3 μm are generated from the nebulizer per minute. Although the patient wearing the nebulizer facemask can inhale some generated droplets, the majority of aerosolized droplets, which are detected by the dust monitor and shown in Fig. 5, can go out from the facemask and disperse in the air. In Fig. 5, particle concentrations and percentages in different particle size ranges are plotted when the male volunteer wears the facemask and pure water is used as drug solution. The sampling points are named according to this principle: "middle", "left", "right" and "front" mean the directions of sampling points on the horizontal plane where the holes on the facemask are located (see Fig. 5(a)). The angle between direction "middle" and "left" is 45°. *D* means the projected distance from a sampling point to the hole on the horizontal plane; *H* means the vertical distance of a sampling point to the horizontal plane. The particle concentrations shown in Fig. 5(b) are the measured values, where the background particle concentration is not subtracted. So the particles include the droplets generated, and may be part of the background particles, as some background particles may collide with the droplets generated, and then attach onto the droplets. From these two figures we can see that more than tens of millions of droplets larger than 0.3 μm can escape from the hole of the nebulizer facemask per minute. When pure water is used, these droplets cannot spread so far away because of complete evaporation.

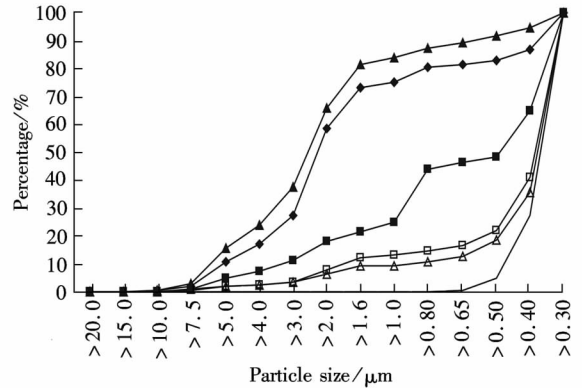
During the experiments we observe that the droplet cloud generated from the saline solution can go 40 cm far away from the nebulizer, which is greater than that of the distilled water droplet cloud. This suggests the possibility of a droplet transmission of infection to other people in the close vicinity of the patient. From the particle concentration results in Fig. 6(b), we can see that the particles can also be detected at



(a)



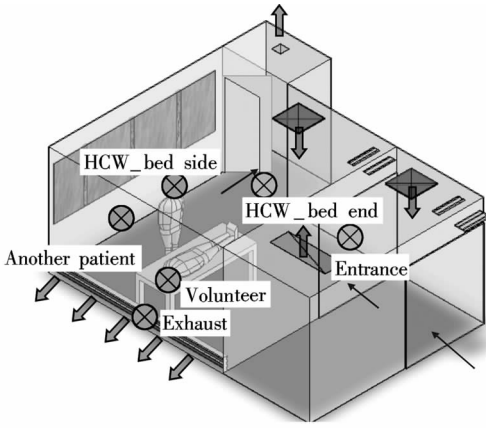
(b)



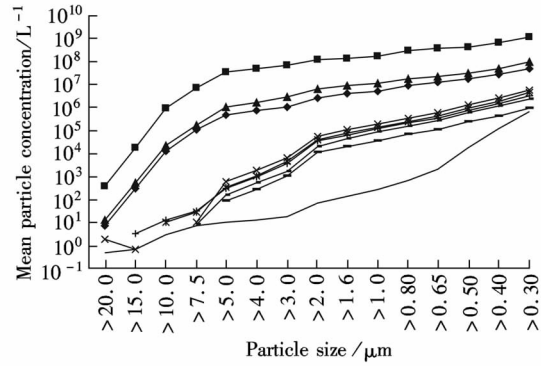
(c)

— Background; — Left,  $D = 10$  cm,  $H = 0$  cm  
— Middle,  $D = 0$  cm,  $H = 0$  cm; — Front,  $D = 10$  cm,  $H = 0$  cm  
— Middle,  $D = 10$  cm,  $H = 0$  cm; — Middle,  $D = 15$  cm,  $H = 10$  cm

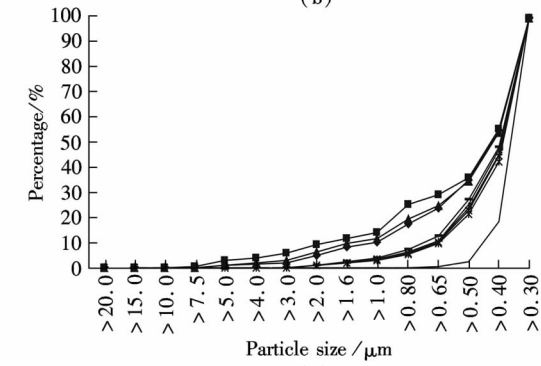
**Fig. 5** Detected particle concentrations and size distributions (male manikin, pure water). (a) Sampling position; (b) Concentration; (c) Percentage



(a)



(b)



(c)

— Background; — HCW\_bed side  
— Middle,  $D = 0$  cm,  $H = 0$  cm; — HCW\_bed end  
— Left,  $D = 10$  cm,  $H = 0$  cm; — Entrance  
— Right,  $D = 10$  cm,  $H = 0$  cm; — Exhaust  
— Another patient

**Fig. 6** Detected particle concentrations and size distributions (male volunteer, 0.9% saline solution). (a) Sampling position; (b) Concentration; (c) Percentage

different positions far from the nebulizer. The percentage curves of Fig. 6(b) shows the size distributions of the particles detected at different positions. The size distributions at the positions of “another patient”, “HCW\_bed side”, “HCW\_bed end”, “entrance”, and “exhaust” are almost the same, while different from those of particles close to the nebulizer and the background. This means that the particles detected at these five positions should not be liquid droplets, but solid particles and the residue of evaporated saline droplets. If the drug solution is contaminated by the secretion from a patient with a respiratory infection, other people (patients and health care workers) inside this room will be at a risk of being infected via airborne routes.

For nebulizer therapy, now the major question regarding infection transmission is whether the reservoir solution can be contaminated by the patient’s secretion during this process. In the case of the SARS outbreak in 2003, the SARS patients were reported to cough and have runny no-

ses. There will be a good possibility that the facemask is contaminated by secretions. Moreover, there are so many droplets inside the mask. Droplets will coagulate not only on the inner surface of the mask, but also on the person’s face, in particular around the nose and mouth. During the experiments, the volunteers feel that there is liquid flowing from the nose down to the mouth after 3 min of using the nebulizer, which makes the volunteers very uncomfortable. We are not sure whether this contaminated liquid can flow back to the drug solution reservoir, and then be aerosolized. Hence we recommend that future work should focus on the study of whether the reservoir solution can be contaminated by the

patient's secretions.

### 3 Conclusion

From our preliminary results it seems that the procedure of taking NPA itself does not generate many droplets. The patient's cough may be the major reason for droplet generation. The cough may be a symptom of the patient's illness, or may be stimulated by this procedure. During nebulizer therapy, more than tens of millions of droplets larger than  $0.3\text{ }\mu\text{m}$  can be generated from the nebulizer per minute. The droplet cloud disperses into the air from two holes on the facemask. The warm exhaled breath and the human body plume as well as the ventilation system have some effects on the movement of the droplet cloud. In some experiments, the droplet cloud is observed to reach a distance of 40 cm. The distance is greater if the patient coughs. When a 0.9% saline solution is used, particles can be detected in the whole room. Droplets coagulate not only on the inner surface of the mask, but also on the volunteer's face. All these suggest that infection can be transmitted by the droplets and the droplet nuclei once the solution is contaminated during nebulizer therapy.

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## 两种医疗操作过程中飞沫的产生

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**摘要:**对2种会产生飞沫的医疗操作过程进行飞沫特性的初步实验研究:鼻咽分泌物(NPA)的抽吸和雾化治疗。抽吸鼻咽分泌物(NPA)时用玻片和水敏感试纸来收集产生的大飞沫,对玻片上飞沫留下的痕迹在显微镜下进行计数,然后进行粒径大小分析。雾化治疗时用粉尘监测仪来检测雾化器周围以及房间中不同位置的小飞沫和飞沫核。研究结果表明,鼻咽分泌物(NPA)的抽吸过程会引发咳嗽,产生大飞沫。雾化器每分钟可产生数千万 $0.3\sim 20\text{ }\mu\text{m}$ 的细小飞沫,其中大部分飞沫会从雾化器面罩上的2个小孔中逸出,扩散到空气中。飞沫在面罩内壁以及志愿者脸上聚集凝结说明雾化治疗过程中药液极有可能被病人的分泌物污染。

**关键词:**飞沫;抽吸鼻咽分泌物(NPA);雾化治疗;疾病传播

**中图分类号:**R183.3; X513