A preliminary experimental study on the user behaviors and aerosol emissions of electric toothbrushes

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Abstract. The oral cavity is a human organ where a high concentration of microorganisms occupies. Evidence has shown that using dental instruments may trigger the release of microbial aerosol indoors. In this paper, the aerosol emissions during the working process of electric toothbrushes were investigated as follows. First, brushing habits, e.g., the favorite brand and flavor of the toothpaste, first tooth/teeth to brush, etc., were determined by 70 questionnaires from university students. Second, typical toothpaste usage per time was determined as 0.3g–0.5g based on a squeezing test by the group. Third, an experimental setup was designed to simulate toothbrushing to measure aerosol emissions. Finally, the measured emissions during toothbrushing were compared with other oral activities. The results showed that the peak PM2.5 emission rate can reach up to 5.9 μg/s by using a typical toothpaste dosage. The number of particles emitted if the incisors were brushed first can be 1–2 times higher than if the molars were firstly brushed. The magnitude of aerosol generated from electric toothbrushing was similar to that of coughing and sneezing.

1 Introduction

Aerosol is of concern because of its small particle size, which can remain suspended in space for long periods to increase the transmission risk of infectious viruses, such as SARS-CoV-2. The human body is one of the sources of aerosol production. For example, the human oral cavity provides an ideal culture medium environment for the growth of microorganisms [1]. Studies have shown that oral-related behaviors such as breathing, coughing, sneezing, and speaking can produce particulate matter which will suspend and cause a risk of spreading viruses [2-4]. In addition, the use of medical devices, such as the various high-speed rotating instruments in a dental surgery, can produce a high concentration of aerosol, which may carry particles of blood, microorganisms, dental materials, saliva, etc. [5]. At present, electric toothbrushes are gaining popularity as personal cleaning products. Similar to the principle of dental treatment instruments and the actions of speaking, sneezing, etc., electric toothbrushes also depend on high-speed vibration and friction to clean a person’s oral cavity. It is possible to produce aerosol and increase the risk of spreading infectious viruses using electric toothbrushes, especially in indoor settings. Moreover, the aerosol emissions may vary depending on a person’s habits and behaviors. However, the literature on user behavior of electric toothbrushes and the corresponding aerosol emissions is still rare. Therefore, this paper conducted a preliminary experimental study to investigate the user behaviors and aerosol emissions of electric toothbrushes.

2 Methods

Aerosol emissions from using electric toothbrushes can be affected by numerous factors involving user behaviors, e.g., the selected toothbrush, the ingredients, usage of the selected toothpaste, the action of toothbrushing, etc. In this preliminary study, we first investigated the preferences for toothbrushing by conducting a survey and a behavior test on a group of university students. Then, we designed an emission test using an oral cavity model to simulate the process of toothbrushing based on the preferences of the students. Finally, the particles generated during the toothbrushing process were compared with other oral activities, such as coughing, sneezing, breathing, speaking, etc.

2.1 Preferences on toothpaste brands and flavors, and the first tooth/teeth to brush

As the first step, questionnaires were sent out to a group of university students aged 21–24 to study their preference for toothpaste brands and flavors, and the first tooth/teeth to brush. As a result, a total of 70 valid questionnaires were received. The results were summarized in Fig. 1. It can be found from Fig. 1 that the preferred brands of toothpaste by the group were YB (initials) and D, the favorite flavor was mint, and the first tooth/teeth for brushing were molars or central incisors.

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2.2 Toothpaste usage measurements

The average toothpaste usage per squeezing was determined by conducting a behavior test (see Fig. 2). First, to simplify the test, one sonic vibration type of electric toothbrush from a popular commercial brand M (the initial) among young students was selected as the carrier. This toothbrush works at a frequency of 33,000 vibrations per minute, with an oscillation of 10°. Because most people tend to wet their toothbrushes before brushing their teeth, the weight of the wetted toothbrush head was controlled at 5.70g±0.01g. Second, 15 volunteers (six females and nine males) were asked to squeeze a tube of toothpaste (of brand D with mint flavor) three times on three wetted heads, respectively. Third, the toothpaste dosage per time can be calculated by subtracting the weight of the wetted head from the total weight of a brush head with squeezed toothpaste on it. Finally, the average usage was determined as 0.3g to 0.5g.

Fig. 2. A behavior test on toothpaste usage.

2.3 Aerosol emission measurements

Based on the survey and the behavior test, an airtight and transparent chamber (600mm×600mm×400mm) made of Alec was set up to simulate the process of toothbrushing in a non-polluted laboratory with closed windows and doors, as shown in Fig. 3. An air purifier was used to ensure that the indoor background particle concentration was low during the experiment. The same electric toothbrush, which was used during the usage tests, was used to brush an oral cavity model. Before, during, and after the brushing, particle sizes in the chamber were measured by two optical particle sizers (TSI Inc., type: 3330). The sampling tube penetrated deep into the chamber through external antistatic rubber hoses. Two sampling ports were fixed to the inside and outside the mouth to ensure that the measurement was close to the brushing position. In addition, temperature, relative humidity data were also recorded using low-cost sensors. Since most of the toothpaste would be used on the first tooth, only the molars or the incisors would be brushed during each test. The main experimental procedures were as follows:

1) Fixing the position of the oral cavity model for the molars or the central incisors to be brushed;
2) Soaking the toothbrush head in a cup of water for 5s to make it wet and ensure that the mass of the toothbrush after wetting was 5.70g±0.02g;
3) Squeezing a designated quality of toothpaste, i.e., 0.3g, 0.4g, or 0.5g, on the head of the toothbrush;
4) Fixing the toothbrush onto a mechanical arm to ensure the brush head into full contact with the teeth;
5) Turning the optical particle sizers on to collect data at a frequency of 1s for a total of 360s;
6) Remotely turn on the toothbrush for 120s;
7) Cleaning the oral cavity model and toothbrush and replacing the air of the chamber;
8) Repeat the procedure 10-15 times using the same amount of toothpaste on the same tooth.

3 Results

3.1 Particle emissions during toothbrushing

The changes in mass concentrations of PM$_1$, PM$_{2.5}$, and PM$_{10}$ during a single test were illustrated in Fig. 4(a), with the two red dotted lines showing the working period of the electric toothbrush. It can be found that mass concentrations of PM$_1$, PM$_{2.5}$, and PM$_{10}$ were all increased significantly after the electric toothbrush was activated, suggesting that a high concentration of aerosol can be generated between the high-speed vibration of the electric toothbrush head and the brushed tooth. Also, PM$_{2.5}$ was selected to demonstrate the emission rates of particles within a typical size during a molar-brushing process using a different toothpaste usage, as shown in Fig. 4(b). The circles represent the mean values, and the upper and lower quartiles represent the upper and lower quartiles. It can be observed that, in
all cases, the emission rates increased rapidly after the electric toothbrush was turned on. Moreover, although the amount of toothpaste dosage varied, ranging from 0.3g, 0.4g, to 0.5g, the emission patterns of PM$_{2.5}$ were similar. The emission rate reached and plateaued at approximately 3.0 μg/s, and the peak emission rate can reach 5.9 μg/s.

Fig. 4. Particle emissions under different conditions.

As shown in Fig. 5, a linear fit can be used to represent the cumulative mass of PM$_{2.5}$ emitted from a typical brushing process with a 0.3g toothpaste dosage by comparing the particle data from the extraoral measurement point (Point 1). The mass of the total particles emitted by brushing incisors was 1–2 times higher than that of brushing molars.

Fig. 5. Accumulation of PM$_{2.5}$ emissions during a typical molar- or incisor-brushing process.

3.2 Particle emission comparisons

Studies have shown that coughing, sneezing, mouth breathing, nasal breathing, and speaking can generate particles with different size distributions and concentration ranges [6-8]. As summarized in Table 1, the particles generated during a typical electric toothbrushing process were compared with other oral behaviors in either quantities or mass concentrations.

The maximum amount of particles emitted during the incisor brushing process was more significant than the molar brushing process. In addition, aerosol emissions from toothbrushing were much more significant than breathing and speaking and were the same magnitude as coughing and sneezing. It indicated that the possible transmission risk from toothbrushing could be similar to these two activities.

Table 1. Brushing VS. other oral behaviors for particulate matter emissions

| Actions        | Mean concentration of particles |
|----------------|---------------------------------|
|                | Quantities (counts/L) | Mass conc. (μg/m$^3$) |
| Brushing molars| 2000–5000          | 5–60             |
| Brushing incisors| 2000–8000      | 50–300           |
| Coughing       | 2000–3000 | n.a.            |
| Sneezing       | 3000–5000 | n.a.            |
| Mouth breathing| 10–100       | 0.001–5         |
| Nasal breathing| 1–15          | n.a.            |
| Speaking       | 10–15         | 0.01–5          |
| Singing        | 100-2000     | 0.1–8           |

Note: n.a. means the data was not found in the literature.

4 Conclusions

In this paper, we investigated the preference of user behaviors of toothbrushing through questionnaires, determined the typical amount of toothpaste by conducting a squeezing test, and measured the particle emissions during an electric toothbrushing process. The major findings were as follows:

1) The toothpaste decomposed rapidly under high-frequency vibration and friction with the teeth during toothbrushing and can produce a high concentration of aerosol. The peak PM$_{2.5}$ emitted during a single 2-min brushing can reach 5.9 μg/s. The PM$_{2.5}$ emitted continues to rise to about 3.0 μg/s in the first 20 s and then enters a relatively steady-state phase.

2) Changes in toothpaste quality have less effect on the particle emission. When the molars were brushed with an electric toothbrush and the mouth was open, the total particle emitted to the environment can reach about 2,000–5,000 particles/L, a number concentration level comparable to the coughing actions sneezing. When brushing incisors, the concentration of emitted particulate matter can even be 1–2 times higher.

3) The order of magnitude of aerosol generated from electric toothbrushing was similar to that of coughing and sneezing, indicating that, to some extent, toothbrushing has the potential to cause transmission of respiratory viruses, especially in a small confined space.
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