Wind Engineering Joint Usage/Research Center
FY2025 Research Result Report

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Research Theme: Dynamics Study on Dental Aerosolization Procedure and Respiratory Cough Generator Using Particle Image Velocimetry and Numerical Simulations

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Budget [FY2025]: 300,000 Yen

*There is no limitation of the number of pages of this report.
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1. Research Aim

This study aims to employ particle image velocimetry (PIV) to analyze the effect of varying human saliva viscosity and surface tension on cough airflow dynamics. Additionally, distributed sensors within the climate-controlled chamber are also utilized to characterize the spatial and temporal evolution patterns of cough aerosol, and the effect of ambient environmental conditions is also revealed.

2. Research Method

The present study was conducted in the multiple-fan climate chamber at Tokyo Polytechnic University (as shown in Fig. 1a), with dimensions of 3.7 m width × 8.0 m length × 2.7 m height. The indoor airflow can be regulated by the 48 plug fans (Fig. 1b) installed in an adjacent fan room. The indoor air velocity is controlled at around 0.1 m/s. The chamber allows for precise environmental control, with temperature and relative humidity (RH) adjustable within the ranges of 20-35 ℃ and 40-70%, respectively. To closely resembling of human cough process, the artificial cough generator was utilized as shown in Fig. 1c. The cough generator can simulate transient expiratory airflow by adjusting the pressure of compressed gas and the opening/closing time of the electromagnetic valve. The cough airflow can be ejected along with the fragmentation of artificial saliva. They would pass through the oral cavity model and be ejected from the opening as a simulated cough. The oral cavity model was a cylinder with a diameter of 4 cm and a length of 13 cm. The mouth opening was 4 cm^2. For all tests, the simulated cough duration was set to 0.2 s, yielding an exhaled air volume of 0.97±0.03 L.

To characterize the dynamics of the cough process, both the PIV visualization and particle concentration measurements were conducted in this climate-controlled chamber. To minimize optical reflections and measurement error during image sequence analysis, the interior surfaces of the chamber will be covered with black cloth with a matte finish. The 2-mm-thick laser light sheet was generated by the Laser G3000 source, with a wavelength of 532 nm. When the cough droplets pass through the laser plane, the scattered light can be captured by the high-resolution camera (FASTCAM Mini AX50). Images were captured across a 0.33 m × 0.16 m field of view with a resolution of 1024 × 496 pixels. Post-processing of the captured images was conducted in the PIVlab software.

Additionally, a thermal manikin (Newton, Measurement Technology North West) was placed in the center of the chamber to mimic a susceptible human subject. The surface temperature of body segments was defined at 34℃. A Testo 405i thermal anemometer was utilized to monitor the air temperature and airflow velocity. The number of suspended aerosols would be measured by two distributed optical particle counters (KANOMAX: Model 3889), with the size bins of 0.3 to 0.5 μm, 0.5 to 1.0 μm, 1.0 to 3.0 μm, 3.0 to 5.0 μm, 5.0 to 10.0 μm, and over 10.0 μm. To evaluate the performance of ambient air

temperature and RH on aerosol concentration, the in-vitro experiments were conducted under six distinct conditions. The temperature settings are in 24℃, 27℃, and 30℃, while the RH levels are controlled at 40% and 70%. Seven saliva samples were utilized in the present study with different viscosities and surface tensions. Saliva A (Liquid-1) is a standard surrogate composed of distilled water, glycerin, and sodium chloride in the mass ratio of 1000:76:12. Saliva B (Liquid-2) utilizes a commercial BioXtra spray (Biopharm), where the hydroxyethyl-cellulose (HEC) is added as a rheological modifier to increase the viscosity. Saliva C (Liquid-5) uses Biotene spray (Biotene® Moisturizing product), which is formulated with Xanthan gum, glycerin, and xylitol to mimic the complex rheological behavior of natural human saliva. The aforementioned two commercial saliva samples have been extensively adopted in medical and dental research. The combination of ethanol (≥99.5% purity, Hayashi Pure Chemical Ind, Ltd.) and glycerol was used to alter the surface tension and viscosity of saliva.

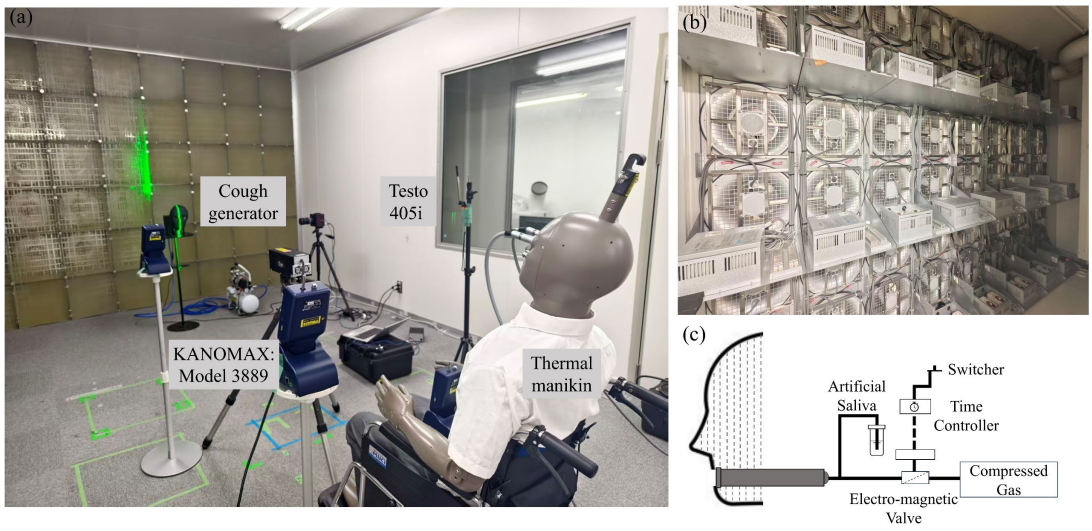

Fig. 1 Schematic diagram of the experimental setup in the multiple-fan climate chamber: a) Configuration of the experiment; b) Multiple fans; c) Artificial cough generator

3. Research Result

Up to now, the data measured during the TPU campaign have only been partially analyzed. The effect of saliva surface tension on the total number of suspended aerosols was also evaluated. Variation in surface tension within the range of 28-68 mN·m^(-1) had little influence on the total number of generated droplets (except in the Tem-27℃-RH-40). Previous studies have reported similar findings, indicating that the surface tension has a negligible impact on the interfacial instability of a jet at high Weber numbers (We). Based on the measurement of cough air velocity (v=11 m/s), air density (ρ =1.2 kg/m^3), characteristic length (l=4 cm), and the surface tension (σ=28 mN·m^(-1)), the Weber number (We=ρv^2 l/σ) can be calculated to be 207. According to the theoretical and experimental literature, a We≥200 can induce the fibre-type ligaments and the secondary liquid break-up. Secondary atomization governs the final droplet size distribution during a cough.

In the present study, the variation factor of the saliva viscosity was roughly 3, ranging from 8 to 27 mPa·s, while the total aerosol concentration could be decreased to 0.51-0.90 times of Liquid-1 (initial level). As the sampling point was located 0.7 m away from the cough generator, variations in aerosol concentration can also be partially attributed to environmental conditions and droplet evaporation. When evaluating the specific effect of viscosity, the highest aerosol concentration was found in the low-viscosity samples (Liquid-1 and Liquid-5). This is because the increased viscosity can delay the breakup of the salvia ligaments, and some beads-on-a-string structures will be directly ejected during the cough process. These results indicate that saliva rheology directly governs the resulting

droplet size distribution.
The practical applications of these research findings can be integrated with the saliva stimulation and environmental control techniques. For example, combining specific food-grade products with mask usage could further reduce the cross-infection risks among human subjects. However, the effect of different products should be carefully investigated. While the usage of sugar-based cough drops can help reduce cough symptoms, they have also been shown to increase droplet formation during the cough process. Overall, our findings suggest that saliva with lower viscosity can increase aerosol generation, thereby promoting airborne transmission. According to the previous studies on human saliva flow rate and rheology, the rheological properties can respond to illness and stress. Manipulating these properties offers a potential mitigation strategy. The present study investigated the saliva viscosity in the range of 8 to 27 mPa·s, whereas the total aerosol concentration can be reduced to 51-90% of its initial level (Liquid-1). Notably, although increased saliva viscosity produces fewer aerosols, it yields larger droplets that may increase fomite transmission risk.

4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]
1. Xiujie Li, Cheuk Ming Mak, Zhengtao Ai, Kuen Wai Ma, Hai Ming Wong. (2025). Composition effect of the dental liquid mixture on droplet evaporation and deposition. Indoor and Built Environment, 34(4), 706-717.
2. Xiujie Li, Cheuk Ming Mak, Kuen Wai Ma, Hai Ming Wong. (2025). Large eddy simulation study on dental spray dynamics and infection during ultrasonic atomization. Journal of Building Engineering, 103, 112164.

[Presentations at academic societies]
1.
2.

[Published books]
1.
2.

[Other]
Intellectual property rights, Homepage etc.

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6. Abstract (half page)

Research Theme: Dynamics Study on Dental Aerosolization Procedure and Respiratory Cough Generator Using Particle Image Velocimetry and Numerical Simulations
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The rheological properties of human saliva are highly responsive to illness and stress, and manipulating saliva properties and environmental conditions could provide a control strategy for airborne transmission. This study investigates how changes in saliva viscosity and surface tension influence the fragmentation, aerosol concentration, and distribution characteristics. In vitro experiments were conducted in a climate-controlled chamber using an artificial cough generator and particle image velocimetry. Seven artificial saliva samples were systematically compared under the six different environmental conditions, with viscosity ranging from 8 to 27 mPa·s and surface tension ranging from 28 to 68 mN·m^(-1). The results indicate that saliva viscosity significantly impacts the fragmentation mechanism, and the variation factor of 3 can decrease the total aerosol concentration to 51–90% of its initial level. Conversely, variations in surface tension had minimal influence on the total number of aerosols. But lowering the surface tension to 28 mN·m^(-1) promoted the generation of ultrafine aerosols smaller than 0.3 μm. Furthermore, the variation in rheological properties could also affect velocity decay profiles of cough airflow. Relative humidity (RH) had a more significant impact on the aerosol concentrations in comparison with the ambient temperature, especially for the RH-40%. The findings indicated that the integration of saliva diagnostics, rheological testing, and environmental control into cross-infection risk models presents a novel approach to further improving public health strategies.