Investigation of the Effectiveness of Infection Control Measures in the Dental Office

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Abstract. Aerosol transmission is an important mode of COVID-19 (SARS-CoV-2) infection. Dentists and dental hygienists, who provide medical treatment and care in the oral cavity, may be exposed to expiratory aerosols of asymptomatic infected persons. To compare the effectiveness of devices in reducing the risk of transmission to dentists and dental hygienists, we conducted experiments in a dental treatment room at Nippon Dental University. The measurements were carried out in five cases: a) the basic case (conventional air conditioning), b) a case with the circulator placed in the center of the room and operated in high air flow mode, c) a case with a circulator placed behind the patient and operated in low air flow mode, d) a case with the circulator blowing from inside to outside, e) a case using an extraoral vacuum, and f) a case with a portable neck fan hanging on the dentist manikin. The results indicated that all measures were effective in reducing the risk of infection, and case e showed the highest reduction in aerosol concentration. However, because extraoral vacuums are expensive, it is important to reduce the risk as much as possible by selecting circulators or portable neck fans according to the budget of each hospital.

1 Introduction

Aerosol transmission is an important mode of COVID-19 (SARS-CoV-2) infection [1]. Dentists and dental hygienists, who provide medical treatments and care in the oral cavity, may be exposed to expiratory aerosols from asymptomatic infected persons without their masks. Although there have been several detailed measurements of aerosol generation during dental procedures and oral cleanings [2, 3], studies on specific measures to reduce the risk of aerosol transmission are limited.

The situation when providing dental care, wherein something near another person's face must be treated without their mask, can be similar to other situations, such as providing food to the elderly and caring for young children. Therefore, clarification of the mechanism of infection and evaluation of risk-mitigation measures in dental treatment situations are expected to make a useful contribution.

In this study, we measured the change in the number of inhaled particles in the breathing zone of dentists to investigate the typical dental treatment situation of aerosol dispersion and clarify the effects of circulators, air purifying filters, and vacuum on reducing the risk of infection for dentists and hygienists.

2 Experimental setup

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2.1 Measurement site

The experiments were conducted in the operating room of the Nippon Dental University Hospital, as shown in Fig. 1. The size of the room was W4.1 m x D6.7 m x H2.6 m. The two dental units were placed in the operating room.

A thermal manikin for the patient and a manikin for the dentist were placed on the window side of the dental unit. The distance between the patient's face and dentist's face was approximately 0.5 m, assuming that the patient was undergoing a dental procedure. Thermal manikin as a patient was operated in the comfort mode, the manikin as the dentist was coiled with an electric wire heater, and heat generation was adjusted to 70 W.

The HVAC system of the operating room is a combination of a ventilation system using an outdoor air handling unit and an air conditioning system using a concealed packaged air conditioner. The air flow rate of the ventilation system is 5.6 ACH (air change per hour), and that of the air conditioning system is 14.7 ACH. Exhaust air was discharged from an adjacent disinfection room through a duct between the operating and disinfection rooms.

2.2 Measurement cases

In this study, ventilation rate measurements and aerosol dispersion measurements were conducted to investigate the effectiveness of circulators, air purification filters, and vacuums in reducing the risk of infection (in Table 1, Fig.2). Case a is the basic condition of conventional air conditioning, case b is the condition in which the circulator was placed at the center of the operating room and operated at high air flow mode, case c is the condition in which the circulator was placed behind the patient and operated at low air flow mode, case d is the condition in which the circulator blew the air from inside the room to the outside of the door in order to increase

<table>
<thead>
<tr>
<th>Case name</th>
<th>Operation condition</th>
<th>Ventilation rate measurement</th>
<th>Aerosol measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-0</td>
<td>HVAC system OFF</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>a-1</td>
<td>HVAC system ON (Basic case)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>b</td>
<td>the circulator placed in the center of the room and operated at high air flow mode</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>c</td>
<td>the circulator placed behind the patient and operated at low air flow mode</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>d</td>
<td>the circulator blows air from inside the room to outside the door</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>e</td>
<td>extraoral vacuum operated near the mouth of patient manikin</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>f</td>
<td>portable neck fan operated hanging on the dentist manikin</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>
the amount of ventilation, case e is the condition in which the vacuum (Tokyo Giken, Arteo-S, suction air volume is 180 m³/h) was operated at a distance of approximately 0.3 m from the patient’s mouth, and case f is the condition in which a neck fan was attached to the doctor manikin.

The circulator, shown in Fig. 3, used in cases b, c, and d, is an experimental prototype to clarify the effectiveness of the circulator and air-purifying filters, and the filters can be detached. In this study, experiments were conducted with and without the filters. The prototype had two fans, the upper one stacked under one, to enable experiments with high air volumes. In cases b and c, both fans were operated in the high air flow mode, while in case d, only the upper fan was operated in the low air flow mode to avoid discomfort caused by the airflow. The detail position of the circulator and airflow rates in each case are summarized in Fig. 4 and Table 2, respectively.

2.3 Measurement method

Measurement items and locations are shown in Table 3 and Fig. 1.

2.3.1 Thermal environment

The outlet and inlet temperatures of the HVAC system and indoor thermal environment were measured continuously at 1 min intervals throughout the measurement period.

2.3.2 Ventilation Efficiency

For cases a-0, a-1, b-1, and d, air change rates were measured using the step-down method. CO2 was used as the tracer gas. CO2 concentration was measured at six locations, as shown in Fig. 1: C1 (the dentist’s breathing zone), C2 (the patient’s breathing zone), C3 (the...
position opposite the doctor across the dental unit, assuming the hygienist’s breath zone), C4 (the chair of the adjacent dental unit), C5 (a corner of the room), and C6 (inlet of air path duct).

2.3.3 Aerosol concentration near the mouth of dentist

In this measurement, aerosols were sprayed from the mouth of the patient manikin, and the number of inhaled particles at P1 (the doctor’s mouth, FL+1.55 m), P2 (the doctor’s hand, FL+1.00 m), P3 (the hygienist’s mouth, FL+1.55 m), P4 (the chair of the adjacent dental unit), and P5 (the inlet of the air path duct) were measured at 10 s intervals for 10 min after aerosol injection. In this study, the same procedure was repeated three times for each measurement case, and the temporal changes in concentration during the evaluation period were ensemble-averaged to evaluate typical temporal changes in aerosol concentration for each case.

In the case of unsteady injection conditions, such as a breath or a cough, the diffusion behavior of the aerosol is not stable owing to instantaneous differences in the flow field at the moment of aerosol injection. Thus, in this study, the same procedure was repeated three times for each measurement case, and the temporal changes in concentration during the evaluation period were ensemble-averaged to evaluate typical temporal changes in aerosol concentration for each case.

3 Results

3.1 HVAC condition and thermal environment

The operational conditions of the HVAC system and thermal environment during the entire measurement period are shown in Figs. 6 and 7. The supply air temperatures were unstable for both the air conditioner.
and the ventilation system. The inlet temperature was approximately 24 ±1°C.

3.2 Ventilation efficiency

Table 4 shows the air change rate evaluated from the time variation of CO2 concentration at each location, and Fig. 8 shows the time variation of CO2 concentration at the doctor's mouth and at the inlet of the duct between the operating room and disinfection room in case d. The air change rate was about 0.6 ACH when the HVAC system was turned off (case a-0) and 1.7-1.8 ACH during the normal air conditioning (case a-1). The measured air change rate was lower than the designed air change rate, but this may be because the disinfection room was open during the measurement. The air change rate in case b was also 1.7 to 1.8 ACH as in normal air conditioning (case a-1), and the circulator was not effective in terms of ventilation efficiency under the present measurement conditions. The air change rate in case d was 9 ACH, and the air change rate was about 5-times higher than in normal air conditioning (case a-1). However, air backflow was observed from the duct between the operating room and the disinfection room.

<table>
<thead>
<tr>
<th>Case</th>
<th>CO2 measurement point</th>
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<tbody>
<tr>
<td></td>
<td>C1</td>
</tr>
<tr>
<td>a-0</td>
<td>0.56</td>
</tr>
<tr>
<td>a-1</td>
<td>1.75</td>
</tr>
<tr>
<td>b-1</td>
<td>1.75</td>
</tr>
<tr>
<td>d</td>
<td>9.39</td>
</tr>
</tbody>
</table>

3.3 Aerosol concentration near the mouth of dentist

The incremental number of particles during the 5 min after aerosol injection at locations P1, P2, P3, and P4 is shown in Fig. 9 for each case.

3.3.1 Case a-1 (Basic case)

At P1 (dentist's mouth), the number of inhaled particles increased and fell rapidly within approximately 1 min after aerosol injection. Thereafter, the number of inhaled particles remained nearly constant during the evaluation period. The peak after aerosol injection occurred because the dense droplets reached the doctor's mouth, and the constant number of inhaled particles after the peak indicates that the aerosol diluted by airflow drifted around the dental unit.

The number of inhaled particles at P2 (doctor's hand) was smaller than that at P1 (doctor's mouth). This result indicates that the droplets diffused upward from the patient's mouth owing to the thermal plume generated by the human body.

The temporal change in the number of inhaled particles at P3 (hygienist's mouth) showed the same trend as that at P1 (dentist's mouth).

No peak was observed at P4 (the chair of the adjacent dental unit), but the number of inhaled particles increased gradually approximately 30 s after the aerosol injection. This indicates that the droplets from the patient were diluted and spread to the adjacent dental unit.

3.3.2 Case b (The circulator placed in the center of the room)

In both cases b-0 and b-1, compared to basic case a-1, the time required for the peak of inhaled particles caused by aerosol injection to decay was reduced at P1 and P3 (dentist's and hygienist's mouths), which means that dentists are exposed to a smaller amount of dense droplets. In case b-1, in the case of the filter, the number of inhaled particles after the peak decreased gradually, whereas the inhaled number of particles after the peak remained almost constant in case a-1.

3.3.3 Case c (The circulator placed behind the patient)

Similar to case b, the time required for the peak of the number of inhaled particles to decay was shortened at P1 (doctor's mouth) compared to case a-1. The peak was not observed at P3 (hygienist’s mouth), which may be due to the location of the circulator in a position where the hygienist was upwind of the patient. In addition, in case c-1, the case with the filter, a gradual decrease in the number of inhaled particles after the peak was observed, but this was not as obvious as in case b-1, because the air flow rate of case c-1 was approximately 1/3 of that of case b-1.

3.3.4 Case d (The circulator blows air from inside the room to outside)

The peak in the number of inhaled particles at P1 (dentist's mouth) was not as large as in other cases, except for case 3, and the number of particles inhaled at P3 (hygienist's mouth) decreased faster than that in a-1. However, since there was air exchange between the operating room and outside in this case, it is impossible to determine the source of the inhaled particles after the peak passed, whether the particles observed were generated aerosols or dust from the outside.
Fig. 9. The incremental number of particles during 5 minutes after aerosol injection at locations P1, P2, P3, and P4 for case (a-1) ~ (f).
3.3.5 Case e (Extraoral vacuum)

There was almost no increase in the number of inhaled particles at any measurement location.

3.3.6 Case f (Neck fan)

The number of inhaled particles at P1 (dentist's mouth) decreased faster than in case a-1. There was no significant difference in the change in the number of inhaled particles compared with Case a-1 at the other measurement locations.

3.3.7 Changes in airflow around the dentist with the introduction of countermeasure devices

Fig. 10 shows the average wind velocity and standard deviation (S.D.) for a total of 30 min for the three evaluation times in each case. In case b, when the circulator was placed in the center of the room, the wind velocity and S.D. increased at a height of the patient's mouth, and in case c, the case where the circulator was placed behind the patient, the wind velocity and S.D. were also increased at the height of the doctor's mouth. In case d, when the circulator was facing out of the window, both the wind velocity and S.D. did not increase at any location. In addition, in case f (extraoral vacuum) and case e (neck fan), both the wind velocity and S.D. did not change at the measurement locations, and the ranges of influence of these devices on airflow were limited to a close area.

4 Conclusion

Several measurements were conducted to clarify the effects of the circulator, air purifying filter, and vacuum, on reducing the infection risk to dentists and hygienists. The following conclusions were drawn from this study.

- Under these measurement conditions, in a normal air-conditioned case, the droplet cloud from the patient remained near the dentist and hygienist for approximately 1 min.
- When an extraoral vacuum was placed at 30 cm from patient’s mouth, the number of inhaled particles was almost zero, suggesting that the risk reduction effect was significant.
- In the three cases, where circulator was placed at different positions in the room, and in the case where a neck fan was attached to the dentist, the time exposed to the droplet cloud was reduced compared to the case with normal air conditioning.
- The use of air purifying filters could remove the diluted droplets remaining in the room, but the effect was not significant when using a filter fan unit with a low air flow rate.
- The results with the circulator indicate that the increase in the background wind speed and its fluctuation contribute to the rapid dilution of the respiratory droplet cloud, leading to mitigation of the risk of infection by aerosols.

References