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Research

Body Map of Droplet Distributions During Oropharyngeal Suction to Protect Health Care Workers From Airborne Diseases

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A B S T R A C T

Purpose: Health care workers (HCWs), and in particular anesthesia providers, often must perform aerosol-generating medical procedures (AGMPs). However, no studies have analyzed droplet distributions on the bodies of HCWs during AGMPs. Therefore, the purpose of this study was to assess and analyze droplet distributions on the bodies of HCWs during suction of oral cavities with and without oral airways and during extubations.

Design: Using a quasi-experiemental design, we assumed the HCWs perform suction and extubation on intubated patients, and we prepared an intubated mannequin mimicking a patient. This study performed the oral suction and extubation on the intubated mannequin (with or without oral airways in place) and analyzed the droplet distributions.

Methods: We prepared a mannequin intubated with an 8.0 mm endotracheal tube, assuming the situation of general anesthesia. We designed the body mapping gown, and divided it into 10 areas including the head, neck, chest, abdomen, upper arms, forearms, and hands. We classified experiments into group O when suctions were performed on the mannequin with an oral airway, and into group X when the suctions were performed on the mannequin without an oral airway. An experienced board-certified anesthesiologist performed 10 oral suctions on each mannequin, and 10 extubations. We counted the droplets on the anesthesiologist's gown according to the divided areas after each procedure.

Findings: The mean droplet count after suction was 6.20 ± 2.201 in group O and 13.6 ± 4.300 in group X, with a significant difference between the two groups ($P < .001$). The right and left hands were the most contaminated areas in group O (2.8 ± 1.033 droplets and 2.0 ± 0.943 droplets, respectively). The abdomen, right hand, left forearm, and left hand showed many droplets in group X. (1.3 ± 1.337 droplets, 3.1 ± 1.792 droplets, 3.2 ± 3.910 droplets, and 4.3 ± 2.214 droplets, respectively). The chest, abdomen, and left hand presented significantly more droplets in group X than in group O. The trunk area (chest and abdomen) was exposed to more droplets during extubations than during suctions.

Conclusions: During suctions, more droplets are splattered from mannequins without oral airways than from those with oral airways. The right and left hands were the most contaminated areas in group O. Moreover, the abdomen, right hand, left forearm, and left hand presented a lot of droplets in group X. In addition, extubations contaminate wider areas (the head, neck, chest and abdomen) of an HCW than suctions.

Health care workers (HWCs) and anesthesia providers in particular, often perform aerosol-generating medical procedures (AGMPs) such as tracheal intubation, oral suction, and tracheal extubation[1,2] and are exposed to a variety of airborne diseases.[3]

In this era of globalization, the high number of worldwide travelers can drive the rapid global spread of new viruses for which little information is available, such as the severe acute respiratory syndrome virus, the middle east respiratory syndrome virus, and

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coronavirus disease 2019 (COVID-19). Discovering the precise transmission route during an initial global outbreak is difficult even in cases when a disease is thought to be transmitted by droplets and aerosols.[4-8] Consequently, HCWs are constantly at risk of being exposed to undiscovered infections. In particular, new viruses transmitted under asymptomatic conditions, such as the COVID-19 virus, can appear anywhere,[9,10] and predicting initial outbreaks to protect HCWs against those infections in advance is impossible.

There are guidelines about applying personal protective equipment (PPE) for HCWs according to the infection route.[11,12] However, HCWs may care for incubation period patients or infected period patients without proper PPE because of lack of patient's information. Furthermore, HCWs may treat the patients without proper PPE due to medical resource shortages. HCWs without appropriate PPE are exposed to droplets during AGMPs and remain under infection threat.[8,13,14] Intubation and extubation procedures are essential for patients who require general anesthesia or mechanical ventilation due to respiratory disease. Before extubation, suction of blood and secretions from the oral cavity prevents airway reflexes such as laryngospasms and maintains the patency of the upper airway including the oropharynx.[15] Thus, analyzing the droplet distribution on HCWs and operating room environments during AGMPs is a prerequisite for planning infection preventive measures for HCWs. However, to the best of our knowledge, no studies have shown droplet distribution maps on HCW gowns during AGMPs. Therefore, we evaluated the distribution of droplets on HCW gowns during AGMPs by mapping the droplets released from mouths of mannequins (with or without oral airways in place) after oral suction and extubation procedures.

Materials and Methods

Subjects and Preparation

We assumed the HCWs perform suction and extubation on intubated patients, and we prepared a mannequin by intubating it with an 8.0 mm endotracheal tube. The cuff pressure was adjusted to 25 to 30 cm H_2O. We dissolved viscous water-soluble paint (simply washable tempera, discount school supply) in water. We inserted 20 mL paint dissolved in water into the mouth of the mannequin to mimic the oral secretions found in patients after anesthesia. The equipment used for suction is as follows. We used a wall suction machine with a pressure between 80- and 100-mm Hg. A suction catheter (latex suction catheter, HC-SC-140, 14-Fr, Bonree Medical) was connected to the wall suction via a suction line. We tested the functionality of the suction catheter with saline solution. An experienced board-certified anesthesiologist (JP) wore a white full-body gown (Protective coverall 4545, 3M) marked with a body section map, gloves, and a face shield (Figure 1). The goal of this research was to analyze the distribution of droplets. Therefore, we designed the body mapping gown, and divided it into 10 areas including the head, neck, chest, abdomen, upper arms, forearms, and hands. The chest and the upper arms are divided by the axilla and humerus head. The upper arms and the forearms are divided by the elbow. The forearms and the hands are divided by the wrist. The chest and abdomen are divided by the xiphoid process (Figure 2).

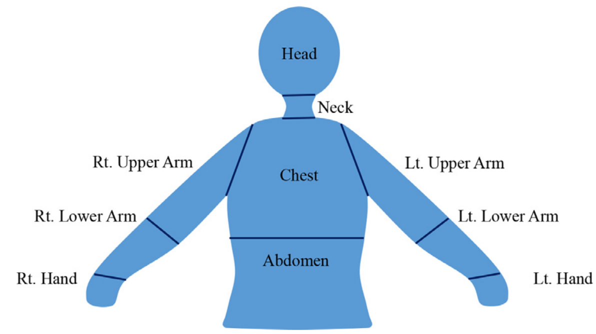

Figure 2. Body mapping gown divided into 10 areas that include the head, neck, chest, abdomen, upper arms, forearms, and hands. This figure is available in color online at www.jopan.org.

Group and Study Protocol

We divided the procedures into two groups: in group O, suctions were performed on intubated mannequins with oral airways (one-piece Guedel airway, size 3, ISO 9.0 Intersurgical); in group X, they were conducted on intubated mannequins without oral airways. An experienced board-certified anesthesiologist performed 10 suctions for each group. The anesthesiologist held the suction line and closed

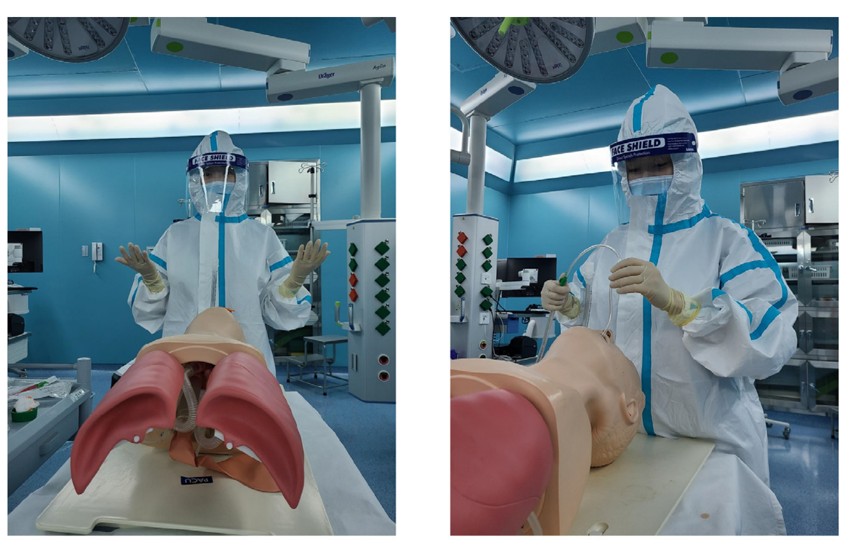

Figure 1. (A) Experienced board-certified anesthesiologist wearing a body mapping gown divided into 10 areas including the head, neck, chest, abdomen, upper arms, forearms, and hands. (B) The anesthesiologist held the suction line and closed the catheter suction hole with the right (Rt) hand, while manipulating the suction catheter with the left (Lt) hand. This figure is available in color online at www.jopan.org.

the hole of the suction catheter with the right hand, while manipulating the catheter with the left hand. The suction catheter was gently inserted into the oral cavity. Then, negative pressure was induced by closing the hole of the suction catheter with a right thumb to suck the viscous, coloured water. Then the suction catheter was slowly and gently moved around the oral cavity during the suction. The suctions were repeated five to ten times until no more paint was visible in the catheter. Other two experienced board-certified anesthesiologists counted the number of colored droplets on the gown in each area after each suction procedure. They counted the droplets with five times magnifying glass (MG4B-6, GSM trade).

In addition, the anesthesiologist also deflated the endotracheal tube cuff and extubated the mannequin after each complete suction procedure. At that point, we also counted the number of droplets on the gown.

Outcome

The primary outcome was the difference in the mean number of droplets on the body gowns between the two groups. The secondary outcome was the distribution of the droplets on the body map areas during oral suctions in both groups. This analysis included a comparison of the number of droplets in the right and left arms. Moreover, we analyzed the droplet distributions after extubations, and we compared the extubations to other two groups.

Statistical Analyses

All data are presented as means ± standard deviations. We assessed normally distributed variables using the Shapiro-Wilk test. The differences between two groups were evaluated using an independent *t* test and Mann-Whitney *U* test. In addition, we compared the right and left upper arms using the same tests. Comparisons of three groups was performed with Kruskal-Wallis test, followed by post hoc testing using Mann-Whitney *U* test. We considered *P*-values <.05 indicative of statistical significance. However, *P*-values <.0167 were significantly different in post hoc testing. Statistical analyses were performed using the IBM SPSS Statistics version 23 software (IBM).

Results

Primary Outcomes

The mean droplet counts were 6.20 ± 2.201 in group O and 13.6 ± 4.300 in group X, with a significant difference between the two groups ($P < .001$). In addition, chest, abdomen, and left hand areas also had significantly fewer droplets in group O than in group X (Table 1).

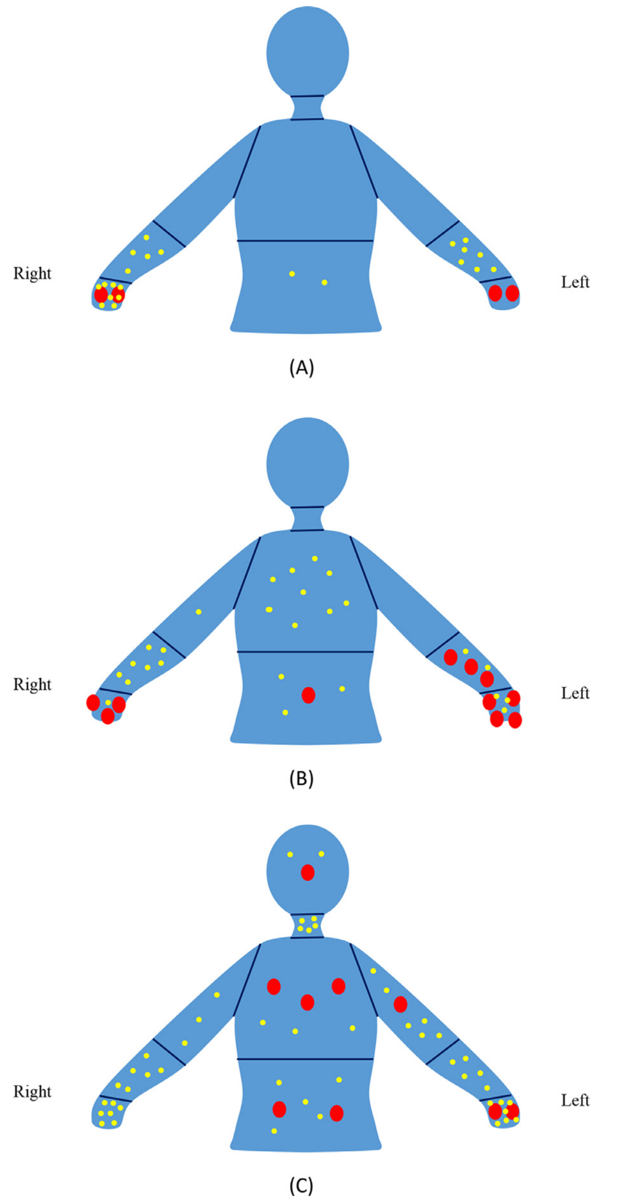

Figure 3. The droplet distributions after suction and extubation (each yellow dot represents a 0.1 droplet and each red dot represents a 1.0 droplet). (A) The regional droplet distributions in group O. (B) The regional droplet distributions in group X. (C) The regional droplet distributions after extubation. This figure is available in color online at www.jopan.org.

Table 1
Comparison of Regional Droplet Distributions Between O and X Groups

	Group O (n = 10)		Group X (n = 10)		
	Mean ± SD	Percentage Difference	Mean ± SD	percentage difference	*P* Value
Head	0 ± 0	0%	0 ± 0	0%	1.000
Neck	0 ± 0	0%	0 ± 0	0%	1.000
Chest	0 ± 0	0%	0.9 ± 0.994	6.62%	.023
Abdomen	0.2 ± 0.632	3.23%	1.3 ± 1.337	9.56%	.029
Rt. upper arm	0 ± 0	0%	0.1 ± 0.316	0.74%	.739
Rt. lower arm	0.5 ± 0.850	8.06%	0.7 ± 0.823	5.15%	.579
Rt. hand	2.8 ± 1.033	45.16%	3.1 ± 1.792	22.79%	.684
Lt. upper arm	0 ± 0	0%	0 ± 0	0%	1.000
Lt. Lower arm	0.7 ± 0.823	11.29%	3.2 ± 3.910	23.53%	.143
Lt. hand	2.0 ± 0.943	32.26%	4.3 ± 2.214	31.62%	.011
total	6.20 ± 2.201	100.00%	13.6 ± 4.300	100.00%	<.001

Table 2
Comparison of Droplet Distributions Between the Right and the Left Arms

	Group O (n = 10)				Group X (n = 10)		
	Right	Left	*P* Value		Right	Left	*P* Value
Upper arm	0 ± 0	0 ± 0	1.000	Upper arm	0.1 ± 0.316	0 ± 0	.739
Lower arm	0.5 ± 0.850	0.7 ± 0.823	.579	Lower arm	0.7 ± 0.823	3.2 ± 3.910	.143
Hand	2.8 ± 1.033	2.0 ± 0.943	.218	Hand	3.1 ± 1.792	4.3 ± 2.214	.199
Total	3.3 ± 0.949	2.7 ± 1.418	.280	Total	3.9 ± 2.025	7.5 ± 3.894	.018

Data represent the mean ± standard deviation (SD).

Secondary Outcomes

Table 1 and Figure 3 present the regional droplet distributions. The head, neck, and left upper arm were not contaminated with droplets. The right and left hands were the most contaminated areas in group O (2.8 ± 1.033 droplets and 2.0 ± 0.943 droplets, respectively). The abdomen, right hand, left forearm, and left hand showed many droplets in group X (1.3 ± 1.337 droplets, 3.1 ± 1.792 droplets, 3.2 ± 3.910 droplets, and 4.3 ± 2.214 droplets, respectively). The chest, abdomen, and left hand presented significantly more droplets in group X than in group O.

In addition, we compared the right and left arm areas (Table 2). We found no significant differences between the arms in group O. However, the left arm was more contaminated than the right arm in group X (*P* = .018).

The trunk (chest and abdomen areas) was exposed to more droplets during extubations than during suctions (Table 3 and Figure 3). Moreover, the head and neck were also contaminated with droplets, whereas the head and neck were not contaminated during suctions.

Discussion

Unexpected infections of HCWs can lead to the collapse of a health care system and cause secondary and tertiary infections in susceptible patients. Thus, HCWs should always be protected from contaminations, particularly during AGMPs, because patients may have unidentified infections (in particular during infectious incubation periods).[16] During AGMPs such as intubations, suctions, and extubations, HCWs are inevitably exposed to droplets and aerosols. Droplets travel approximately 1 meter, and a safe distance to avoid them is 2 meters from their source.[17] However, HCWs cannot avoid proximity to their patients during AGMPs.[13,18] Lockhart et al. present the PPE guidelines for HCWs.[11] PPE for droplet and contact precautions consists of a surgical mask, eye protection, and Association for the Advancement of Medical Instrumentation (AAMI) level-2 gown, and single gloves. In addition, PPE for airborne, droplet, and contact precautions includes head covering, eye protection, N95 respirator, an AAMI level-2 gown, and single gloves. They recommend additional neck covering, a gown with AAMI level-3, and two sets of gloves for HCWs only directly involved in the high-risk AGMPs. Donning proper PPE is the most effective method to prevent infection from infected patients. However, applying full PPE for every AGMP even in patients who are not known infectious is impractical due to limitations of medical resources and accumulation of HCWs' fatigue.[17,19,20] Moreover, HCWs sometimes treat patients in the incubation period or infection periods without proper PPE due to the lack of information on patient's disease status, especially during a pandemic.[21-23] Therefore, research on the distribution of droplets during AGMPs is necessary to implement HCW protections based on accurate information.

In this study, we quantified the number of droplets on body mapping gowns after suction and extubation procedures. Our primary findings were that there were fewer total splattered droplets after suction of mannequins with oral airways than without oral airways. Oral airways secure the space in the oral cavity and allow the suction catheter to easily enter and exit the mouth. The suction catheter can reach the oropharynx with less resistance when an oral airway is in place, and the secretions can be fully suctioned in a small number of movements without having to execute complicated manoeuvres. Therefore, HCWs get fewer contaminating droplets when the oral cavity has an oral airway in place. In the group without oral airways (group X), controlling the suction catheter was more difficult and led to more droplet contamination due to the narrower oral cavity width in the absence of an oral airway. The catheter manipulation without an oral airway in place requires more movements for sufficient suction and consequently more droplets get splattered.

In group X, the left arm holding the suction catheter was more contaminated with droplets than the right arm holding the suction

Table 3
Comparison of the Regional Droplet Distributions Between the Group O, the Group X and Extubation

	Group O (n = 10)		Group X (n = 10)		Extubation (n = 10)					
	Mean ± SD	Percentage Difference	Mean ± SD	Percentage Difference	Mean ± SD	Percentage Difference	*P* Value*	*P* Value†	*P* Value‡	*P* Value§
Head	0 ± 0	0%	0 ± 0	0%	1.20 ± 1.687	8.63%	.003	1.000	.063	.063
Neck	0 ± 0	0%	0 ± 0	0%	0.5 ± 0.707	3.60%	.012	1.000	.143	.143
Chest	0 ± 0	0%	0.9 ± 0.994	6.62%	3.3 ± 0.949	23.74%	<.001	.023	<.001	<.001
Abdomen	0.2 ± 0.632	3.23%	1.3 ± 1.337	9.56%	2.5 ± 1.434	17.99%	.001	.029	.001	.075
Rt. upper arm	0 ± 0	0%	0.1 ± 0.316	0.74%	0.3 ± 0.675	2.16%	.330			
Rt. lower arm	0.5 ± 0.850	8.06%	0.7 ± 0.823	5.15%	0.6 ± 0.843	4.32%	.785			
Rt. hand	2.8 ± 1.033	45.16%	3.1 ± 1.792	22.79%	0.7 ± 0.949	5.04%	.001	.684	.001	.004
Lt. upper arm	0 ± 0	0%	0 ± 0	0%	1.6 ± 2.221	11.51%	.012	1.000	.143	.143
Lt. Lower arm	0.7 ± 0.823	11.29%	3.2 ± 3.910	23.53%	0.5 ± 0.972	3.60%	.086			
Lt. hand	2.0 ± 0.943	32.26%	4.3 ± 2.214	31.62%	2.7 ± 2.003	19.42%	.037	.011	.353	.143
total	6.20 ± 2.201	100.00%	13.6 ± 4.300	100.00%	13.9 ± 6.064	100.00%		<.001	<.001	.853

* Comparison of Group O, Group X and extubation.
† Comparison of Group O and Group X.
‡ Comparison of Group O and extubation.
§ Comparison of Group X and extubation.

line because the left arm remained closer to the oral cavity during the procedure (Table 2). Moreover, the right hand, and especially the right thumb closing the suction catheter hole, was one of the most contaminated areas in both groups (Table 1). The suctioned secretions contaminated the right hand through the catheter hole, particularly the right thumb.

During extubations, the chest and abdomen were the most contaminated areas. In addition, the head and neck were also contaminated with droplets, whereas those areas were not contaminated during suctions. These results demonstrate that the extubation process splatters droplets more widely than suctions and that it contaminates the torso more than the arms.

There are guidelines about applying PPE for HCWs according to the infection route.[11,12] Nevertheless, HCWs may encounter incubation period patients or infected period patients without proper PPE because of lack of patient's information or medical resource shortages. Previous studies suggest the methods using clear plastic drapes, tents, or aerosol protection boxed in case during AGMPs.[22,24-26] These methods aim to reduce the risk of viral transmission rather than to replace PPE. These methods are applicable for HCWs who care for incubation or infected patients without proper PPE to reduce the possibility of infection, and they supplement the current guidelines. Although these methods for preventing infection are suggested, there are no studies proving the effectiveness of the methods. Therefore, before presenting a method to protect HCWs from droplets, it is important to first understand how contaminating droplets spread and fall on HCWs. We assessed this issue.

A body mapping gown which the authors designed and divided it into 10 areas including the head, neck, chest, abdomen, upper arms, forearms, and hands is a great tool for analyzing droplet contamination, and was used in this study. It can be used to investigate droplet distributions in a variety of situations in further studies. Moreover, by quantifying droplet distributions on a body mapping gown, researchers can test the efficacy of new protection methods.

In this study, we compared the splattered droplets on HCW gowns when performing AGMPs on intubated mannequins with or without oral airways in place. In addition, we evaluated the droplet distributions on the gowns during extubations. Our results provide information on HCW contaminations and propose methods for preventing infections with diseases transmitted through droplets. At first, an oral airway application can reduce the spread of droplets according to this study's results. Moreover, it would be reasonable for HCWs to wear a barrier gown over their scrubs when suctioning, even in patients who are not known infectious, to be prevented exposure and possible transmission to other patients. For example, disposable arm sleeves during suctions are helpful to protect the HCWs because arms and hands are the most contaminated areas during suction (Table 3 and Figure 3). In addition, head, neck and chest cover can be useful for HCWs during extubation which provides the high number of droplets on HCWs' chest (Table 3 and Figure 3). Further studies need to investigate other factors that affect droplet distributions. Based on our results, we can plan studies on real patients that will have clinical implications.

The clinical implications of the present study are as follows. First, the study results present several methods to protect HCWs from droplet contamination. The application of oral airway reduces the droplet spray. Oral airways are easily applicable for intubated patients during suction, and the study's result is valuable. The results from regional analysis with body mapping gown suggest the barrier gown for specific parts of HCWs such as arm sleeves and chest cover. These methods supplement the current guidelines for situations when HCWs cannot don proper PPE. Second, the body mapping gown presented in this study can be used to analyze the droplet distribution in various situations in further studies.

There are several limitations to this study to mention. First, we performed the suction and extubation tests on mannequins that can only imitate human morphology, but do not reflect human behaviors such as coughing and uncooperative movements (which can increase the amounts of splashing droplets). Therefore, our results may not entirely reflect the situation in patients. Second, the paint dissolved in water has different viscosity from that of real secretions in a patient's oral cavity. However, we tried to produce a solution with a similar viscosity by adjusting the ratio of water and paint (water: paint, 5: 1). Third, only one physician (JP) performed the experiments and his personal skills probably affected the droplet distributions. Nevertheless, the physician is an experienced board-certified anesthesiologist with thousands of times of suction experience, and his abilities probably represent those needed during general suction and extubation procedures. In further studies, multiple providers participate in performing AGMPs and the value of study results can be enhanced. Fourth, no previous studies have focused on droplet distributions on HCW gowns during AGMPs, and we could not calculate a representative sample size base on previous data. Therefore, we determined the sample size at our own discretion and the size may have not been enough to accurately evaluate the droplet distributions and the differences between groups. Nonetheless, our results showed significant differences in the numbers and distributions of droplets between the two groups. Fifth, we only counted the number of droplets, which does not represent the total amount of contaminants because the droplet sizes differ. There are several studies to present the methods of measurement of droplet volume. Optical particle counter, digital PCR, a stroboscopic technique or electrode-based volume metering can be used to accurately measure droplet volume or count.[27-30] However, we could not apply these precise volume measuring methods because of the limitation of the necessary equipment. Therefore, we chose the counting droplets method which is easily applicable without specific devices. Accurately measuring droplets distribution method is needed in further studies. Sixth, we investigated only visible droplets. Generally, a particle larger than 5 μm is classified as a droplet, and a particle smaller than 5 μm is an aerosol.[31] Respiratory droplets generally predominate over aerosols in many respiratory viruses' transmissions.[4,31,32] Therefore, droplet precautions are important before an etiology is identified.[31] Consequently, we believe the present study on droplet distributions is valuable.

Conclusion

During suctions, more droplets are splattered from mannequins without oral airways than from those with oral airways. The right and left hands were the most contaminated areas in group O. Moreover, the abdomen, right hand, left forearm, and left hand presented a lot of droplets in group X. In addition, extubations contaminate wider areas of an HCW, including the torso (head, neck, chest, and abdomen), with droplets than suctions.

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