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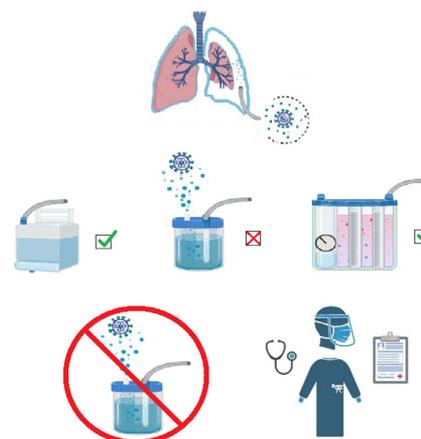
# Simulation and Measurement of Aerosolisation in Different Chest Drainage Systems

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The aim of the study was to assess the degree of aerosolisation in different chest drainage systems according to different air leak volumes, in a simulated environment. This novel simulation model was designed to produce an air leak by passing air through and agitating a fluorescent fluid. The air leak volume and amount of fluorescent fluid were tested in various combinations and aerosolisation was assessed at 10-minute intervals using the ultraviolet light. The following chest drainage systems were compared: (1) single-chamber chest drainage system, (2) 3-compartment wet-dry suction chest drainage system, (3) digital drainage and monitoring system. The impact of suction (–2 and –4 kPa) in generating aerosolised particles was tested as well. A total number of 187 of 10-minute interval measurements were performed. The single-chamber chest drainage system generated the largest number of aerosolised particles at different air leak volumes and drainage output. The 3-compartment wet-dry suction system and the digital drainage and monitoring system did not generate any identifiable aerosolised particles at any of the air leak or drain output volumes considered. Suction applied to the chest drainage systems did not have an effect on aerosolisation. Aerosol generation in the simulated air-leak model demonstrated the potential risk of SARS-CoV-2 spread in the clinical setting. Full personal protective equipment must be used in patients with an air leak. Single-chamber chest drainage system generates the highest rate of aerosolised particles and it should not be used as an open system in patients with an air leak.

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**Keywords:** COVID-19, Air leak, Aerosolisation, Viral spread, Cardiac surgery, Thoracic surgery



Air leak and chest drain: Potential for COVID-19 transmission due to aerosolised particles

## Central Message

Aerosolisation was demonstrated in the simulated air-leak model. No current chest drainage system can eliminate the risk of SARS-CoV-2 spread, and use of closed systems and viral filters is essential.

## Perspective Statement

An air leak in ventilated patients with ARDS or after thoracic surgery is considered as a risk of SARS-CoV-2 spread. Cautious chest drain management is important to prevent iatrogenic spread of infection. This experimental model focused on assessing the impact of an air leak volume, drain output and chest drainage system on generating aerosolised particles and potential disease transmission.

**Abbreviations:** AGP, aerosol-generating procedures; ARDS, acute respiratory distress syndrome; BTS, British Thoracic Society; CDS, Chest drainage system(s); COVID-19, Coronavirus disease 2019; DD-CDS, Digital drainage and monitoring chest drainage system; PPE, personal protective equipment; SARS-CoV-2, Severe acute respiratory syndrome coronavirus 2; SC-CDS, Single-chamber chest drainage system; TC-CDS, Three-compartment wet-dry suction chest drainage system; WHO, World Health Organisation

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## BACKGROUND

SARS-CoV-2 is contagious in the early phase of the infection, even in asymptomatic patients; and a lot of emphasis has been recently put on preventing the spread of the virus.<sup>1</sup> Several measures such as social distancing, masks and gloves have been considered to minimise the risk of spread.

The ways of transmission of the SARS-CoV-2 virus causing the ongoing pandemic are still uncertain. Although it has been confirmed that the virus is transmitted via direct contact with fomites containing respiratory droplets (aerosolised particles >5–10 micrometers in size), the transmission via inhalation of droplet nuclei (fine aerosolised particles <5 micrometers in size) is still considered to be possible.<sup>1,2</sup> The health authorities, including World Health Organisation, reserve full personal protective equipment (PPE) while performing aerosol-generating procedures (AGP) such as intubation, extubation, cardiopulmonary resuscitation etc. in every patient considering the rate of 20%–30% of false-negative swabs.<sup>3,4</sup>

During the COVID-19 crisis, up to 20%–42% of patients have developed acute respiratory distress syndrome.<sup>5,6</sup> These patients had to be intubated and ventilated aggressively often causing a degree of volutrauma and/or barotrauma to the lungs with subsequent development of pneumothorax and air leaks. Chest drain insertion was indicated in the majority of COVID-19 -positive patients with pneumothorax and other complications of mechanical ventilation, such as pneumomediastinum, subcutaneous emphysema, and tracheal injury.<sup>7,8</sup> The main concern in these patients is the aerosolised particles generated in the chest drain systems (CDS) with potential spread of the SARS-CoV-2 to other patients and healthcare workers.<sup>9,10</sup>

Similarly, patients operated on for any thoracic condition during the pandemic have posed a clinical issue in terms of managing their postoperative air leak, considering “on suction” versus “off suction” mode, especially in the patients who are discharged home with a chest drain in situ due to a prolonged air leak. Normally, the “off suction” management of the chest drains is usually recommended in those patients.<sup>11</sup> However, the environmental spread of the SARS-CoV-2 from the chest drain in a household remains a concern.<sup>12</sup>

At the start of the pandemic, the British Thoracic Society has issued the recommendation to use closed CDS to prevent a release of contaminated aerosol droplets from the open ports of the systems.<sup>13</sup>

This recommendation poses a challenge in managing patients with air leaks as the only way to keep a CDS closed safely is by connecting it to the wall suction. On the other hand, the wall suction may prolong the duration of an air leak, particularly in severely emphysematous lungs, reduces postoperative mobility, and increases the risk of atelectasis and pneumonia. In view of this challenge, some authors proposed a breathing filter to be connected to the open port of the CDS.<sup>9</sup>

To date, there is no clear evidence of whether the air leak actually produces the aerosolised particles and how the CDS affect the amount of aerosolised particles released in the environment; hence there is an unconfirmed theoretical risk of the

SARS-CoV-2-containing aerosols escaping from the CDS of COVID-19-positive patients.

There are questions to answer whether the air leak from the chest drains generates aerosolised particles, whether its volume plays any role in producing the aerosols, and whether the closed systems are superior in preventing possible contamination of the environment over the open systems.

The aim of the study is to assess the degree of aerosolisation from different CDS with various volumes of air leak in presence of fluid in a simulated environment.

## MATERIAL AND METHODS

The simulation was conducted at the simulation centre outside a clinical setting and did not require an ethical approval.

This novel simulation model was designed to generate different volumes of continuous air leak by passing air through and agitating a fluorescent fluid. The aerosolised particles of the fluorescent fluid collected inside the suction port of a CDS and outside were registered in the ultraviolet light.

The conditions of the simulation were as close to real as possible within the practicability and safe limits of the used systems prescribed by a manufacturer.

The following CDS currently in use in our institution were compared:

- 1) Single-chamber chest drainage system (SC-CDS) (Rocket Blue Bottle, Rocket Medical plc, United Kingdom),
- 2) Three-compartment wet-dry suction system (TC-CDS) (Redax Drentech Variant, Redax, Italy),
- 3) Digital drainage and monitoring system with regulated suction pressure (DD-CDS) (Thopaz+, Medela Healthcare, Switzerland).

The SC-CDS was primed with 500 mL (zero level /water seal valve) of fluorescent fluid (Detect+White tracer, Fluotechnik, France) at a room temperature whereas the TC-CDS required 45 mL of fluorescent fluid for priming only. The DD-CDS did not require priming.

The various amounts (100 mL, 200 mL, up to 2000 mL) of warm fluorescent fluid at 36 degrees Celsius mimicking the pleural drain output were added to the drain systems every 10 minutes during the simulation, until the maximum drainage capacity was reached, and in particular: 1800 mL for the SC-CDS, 2000 mL for the TC-CDS and 300 mL for the DD-CDS.

The air leak (wall oxygen) volumes were set at 0.5, 1, 2, up to 8 L/min and the results were analysed at 10-minute intervals. The main part of the simulation was conducted off suction, whilst the suction of –2 and –4 kPa (–20 and –40 cm H<sub>2</sub>O) negative pressure was used at the end of the simulation (air leak volume above 8 L/min) in order to confirm absence of aerosolisation.

The detection of the generated aerosol particles was performed using the ultraviolet flashlight kit (UV wavelength 365 nm, Fluotechnik, France) to identify fine and large droplets of the fluorescent liquid outside the drainage systems. The

photographs of the droplets were then taken using iPhone X (Apple Inc, Cupertino, California) and their sizes were measured using the MATLAB software (Mathworks Inc, Massachusetts).

The sizing script was based on the Circle Hough Transform using Atherton and Kerbyson's Phase Coding method where each detected aerosol particle was identified, calculated and scaled according to the pixels in the image within the chosen region of interest.<sup>14</sup> A threshold was set so that the program identified circles' radii in the range of 26.67  $\mu\text{m}$  to 533.4  $\mu\text{m}$  (1 to 20 pixels), and the original image was produced with labeled particles.

**RESULTS**

A total number of 187 measurements of 10-minute intervals of the simulation were performed (setup shown on Fig. 1).

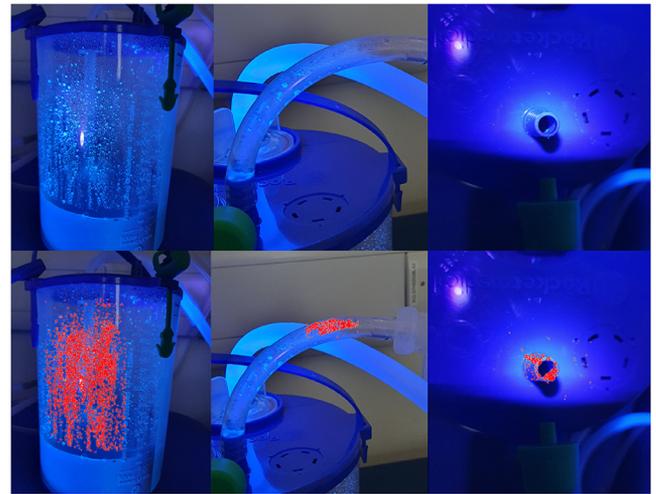
The SC-CDS was confirmed to generate the aerosolised particles (vapour and fine droplets) at various air volumes and levels of the fluorescent fluid in the drain through the open port (Fig. 2). For instance, with the priming fluid level (500 mL) only and no pleural fluid collection, an air leak volume of as high as 8 L/min was required in order to generate aerosolised particles, whereas a fluid level of 300 mL added to the priming volume generated aerosols already at 3 L/min. After adding 600 mL of content on top of the priming level, the aerosolised particles were generated at 0.5 L/min of air leak volume (see Table 1).

On measurement of the SC-CDS aerosolisation, 143 particles were detected in the selected region of interest (the chamber top, inside, and around the open port). The mean particle diameter was  $152.40 \mu\text{m} \pm 104.45 \mu\text{m}$  (range, 56.39–659.43  $\mu\text{m}$ ) with the smallest particle 56.39  $\mu\text{m}$  in diameter. Particles identified in that range were labeled with red color in the original image (Fig. 2, bottom row).

The TC-CDS did not generate any aerosolised particles neither inside the open port nor around the safety valve, within



**Figure 1.** Setup of the simulation with three different CDS: TC-CDS (left), SC-CDS (middle), and DD-CDS (right).



**Figure 2.** Aerosolisation in the SC-CDS: the droplets are detected inside the canister, inside the endotracheal tube (connected for demonstration purposes) and the suction port (top row photos, left to right). The aerosolised particles are measured using a phase coding method (red circles, bottom row photos).

the whole scope of the simulation (air leak volume range, 0.5–6 L/min, fluid content 100 mL–2000 mL) (Fig. 3, Table 2).

Neither the DD-CDS generated the aerosolised particles around the exhaust holes, within the scope of the conducted simulation (air leak volume range, 0.5–5 L/min, fluid content 100 mL–300 mL) (Fig. 4, Table 3).

Suction applied to the chest drainage systems did not have an effect on aerosolisation.

**DISCUSSION**

Aerosolisation is the complex process and depends on many factors, including temperature and surface tension of the medium (water or bodily fluids), humidity, evaporation of droplets, aggregation of the virus, and others.

Considering the small size of viruses, for example, influenza A virus is 80–120 nm, chickenpox virus is 150–200 nm and SARS-CoV-2 is 65–125 nm (0.065–0.125 microns) in diameter, a respiratory droplet of 10 microns, and above can potentially carry a large amount of virus during the peak of infectivity.<sup>15</sup> The viruses in nature exist in aggregations, attached to the carrying material and encased by droplets. Altogether, aerosolisation of the medium and aggregation of the virus create a significant potential to travel distances in air: droplet nuclei as smaller particles remain in air longer than large droplets, then shrink and settle down as dust particles containing the virus.

In the light of the current COVID-19 pandemic and the concern regarding AGP, the chest drain management has been scrutinised in order to minimise the risk of exposure to other patients and the health professionals. So far, no CDS has been specifically tested for SARS-CoV-2 transmission or

**Table 1.** Aerosolisation in the SC-CDS (marked as yellow colour)

Single-chamber chest drainage system						
Trial #	Air flow, L/min	Suction, kPa	Priming fluid, mL	Temperature of priming fluid, Celcius	Duration of exposure, min	Aerosolisation (N-None, Y-Detected)
1	0.5	0	500	20	10	N
2	1	0	500	20	10	N
3	2	0	500	20	10	N
4	3	0	500	20	10	N
5	4	0	500	20	10	N
6	5	0	500	20	10	N
7	6	0	500	20	10	N
8	7	0	500	20	10	N
9	8	0	500	20	10	Y

Single-chamber chest drainage system						
Trial #	Air flow, L/min	Suction, kPa	Drain output, mL	Resulting temperature of fluids, Celcius	Duration of exposure, min	Aerosolisation (N-None, Y-Detected)
28	0.5	0	300	26	10	N
29	1	0	300	26	10	N
30	2	0	300	26	10	N
31	3	0	300	26	10	Y
32	4	0	300	26	10	Y
33	5	0	300	26	10	Y
34	6	0	300	26	10	Y
35	7	0	300	26	10	Y
36	8	0	300	26	10	Y

Single-chamber chest drainage system						
Trial #	Air flow, L/min	Suction, kPa	Drain output, mL	Resulting temperature of fluids, Celcius	Duration of exposure, min	Aerosolisation (N-None, Y-Detected)
55	0.5	0	600	28	10	Y
56	1	0	600	28	10	Y
57	2	0	600	28	10	Y
58	3	0	600	28	10	Y
59	4	0	600	28	10	Y
60	5	0	600	28	10	Y
61	6	0	600	28	10	Y
62	7	0	600	28	10	Y
63	8	0	600	28	10	Y

Resulting temperature of fluids is the derivative temperature after mixing drain output (36 degrees Celsius) with the priming fluid (20 degrees Celsius).

aerosolisation. The DD-CDS has an antibacterial filter but was not specifically tested for viruses.

Knowing that 20%–30% of patients, even if tested negative, might be infected when assessed for elective surgery (false negatives) as well as assessing the COVID-19 patients needing an urgent chest drain insertion, every patient with a chest drain or post thoracic procedure should be considered a potential source of viral spread and should be managed accordingly.

Guidelines and recommendations have been issued, identifying a chest drain insertion as an AGP despite the little evidence supporting this view. On pragmatic basis, the British

Thoracic Society guidelines suggested to use a closed system with a wall suction to minimise the release of aerosolised particles into the environment.

As our institution is one of the largest thoracic units in the United Kingdom, we aimed to address safe management of the CDS in the patients post elective thoracic surgery and to minimise the risk of spread of SARS-CoV-2 after any thoracic intervention.

Considering the lack of evidence, we decided to test the available CDS to quantify objectively the aerosolised particles generated within the CDS.



**Figure 3.** No evidence of aerosolisation from either the open port or safety valve (crossed window) of the TC-CDS at maximum settings (2 L of fluid level and 6 L/min of air leak volume). The endotracheal tube is connected to the open suction port of the system for demonstration purposes.

Currently, there is a wide range of CDS on the market; however, we chose 3 conceptually different systems according to the evolution of chest drainage, from simple, one-container CDS through to the TC-CDS, and to the DD-CDS with regulated suction pressure. These different systems realise different approaches to how the drainage is carried out<sup>16,17</sup> and we assumed they have different safety profile in terms of infection transmission. The volume of an air leak, the drain output level and the type of the system were evaluated as potential factors affecting the aerosolisation and contamination of the environment.



**Figure 4.** No evidence of aerosolisation from the exhaust holes of the DD-CDS at maximum settings (300 mL of fluid level and 5 L/min of air leak volume). The canister is removed as the drainage system is tilted over.

In our model depicted in the graphical abstract, the SC-CDS showed an increased release of aerosolised particles in the environment through the open port of the system. The number of

**Table 2.** Absence of Aerosolisation in the TC-CDS With Different Drain Output Levels and Suction Pressures

Three-compartment drainage system						
Trial #	Air flow, L/min	Suction, kPa	Priming fluid, mL	Temperature of priming fluid, Celcius	Duration of exposure, min	Aerosolisation (N=None, Y=Detected)
64	0.5	0	45	20	10	N
65	1	0	45	20	10	N
66	2	0	45	20	10	N
67	3	0	45	20	10	N
68	4	0	45	20	10	N
69	5	0	45	20	10	N
70	6	0	45	20	10	N

Trial #	Air flow, L/min	Suction, kPa	Drain output, mL	Resulting temperature of fluids, Celcius	Duration of exposure, min	Aerosolisation (N=None, Y=Detected)
113	0.5	0	2000	36	10	N
114	1	0	2000	36	10	N
115	2	0	2000	36	10	N
116	3	0	2000	36	10	N
117	4	0	2000	36	10	N
118	5	0	2000	36	10	N
119	6	0	2000	36	10	N
127	0.5	-4	2000	36	10	N
128	1	-4	2000	36	10	N
129	2	-4	2000	36	10	N
130	3	-4	2000	36	10	N
131	4	-4	2000	36	10	N
132	5	-4	2000	36	10	N
133	6	-4	2000	36	10	N

**Table 3.** Absence of Aerosolisation in the DD-CDS With Different Drain Output Levels and Suction Pressures

Digital drainage and monitoring system						
Trial #	Air flow, L/min	Suction, kPa	Drain output, mL	Temperature of fluid, Celcius	Duration of exposure, min	Aerosolisation (N-None, Y-Detected)
146	0.5	-0.8	300	36	10	N
147	1	-0.8	300	36	10	N
148	2	-0.8	300	36	10	N
149	3	-0.8	300	36	10	N
150	4	-0.8	300	36	10	N
151	5	-0.8	300	36	10	N
176	0.5	-4	200	36	10	N
177	1	-4	200	36	10	N
178	2	-4	200	36	10	N
179	3	-4	200	36	10	N
180	4	-4	200	36	10	N
181	5	-4	200	36	10	N
182	0.5	-4	300	36	10	N
183	1	-4	300	36	10	N
184	2	-4	300	36	10	N
185	3	-4	300	36	10	N
186	4	-4	300	36	10	N
187	5	-4	300	36	10	N

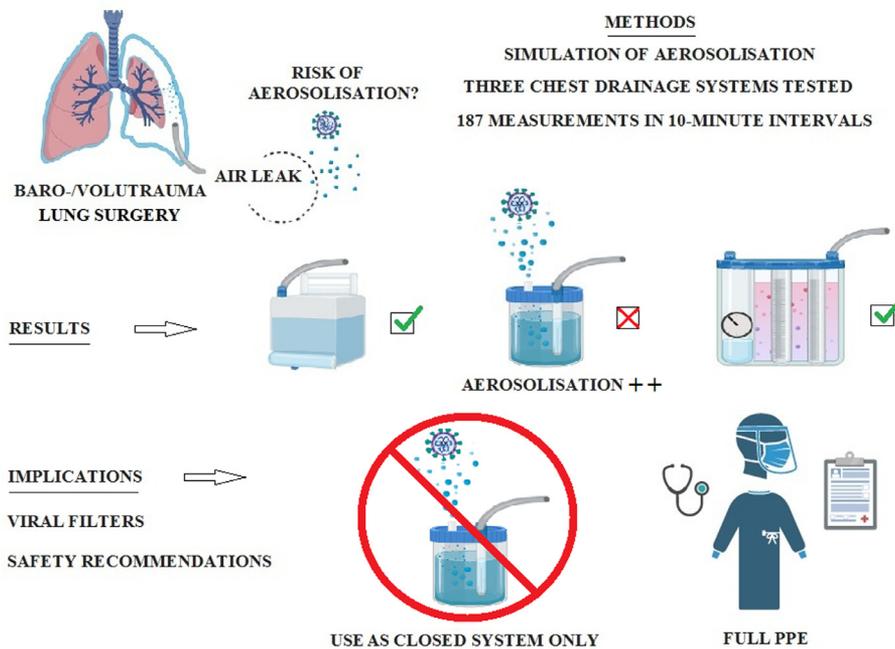
particles correlates with air leak volume and amount of the pleural fluid in the drainage system.

The higher amount of the pleural fluid in the SC-CDS requires lower air leak volume to generate aerosols, hence, the system reservoir should be changed often, ideally once the level of the fluid reaches 300 mL (on top of the priming volume of

500 mL). This should be done with all necessary precautions (full PPE etc.) and the SC-CDS when in use should be kept closed by connection to wall suction.

Based on our findings, the TC-CDS and DD-CDS did not show any aerosolised particles; neither the amount of fluid had any impact on these CDS (Fig. 5).

**AIR LEAK AND CHEST DRAIN: POTENTIAL FOR COVID-19 TRANSMISSION DUE TO AEROSOLISED PARTICLES**



**Figure 5.** Background and setup of the simulation, including methods, results and implications of the study.

This could be explained by many factors, including the design of the each tested drainage system: in a SC-CDS, the chamber provides a water seal and has a port open to the ambient air, and the air leak-generated aerosols are released directly into the atmosphere, whereas the TC-CDS has an intermediate water-seal chamber as well as the third, suction chamber preventing aerosol release to the atmosphere. The DD-CDS has a sophisticated design of the closed system with an antibacterial filter before the exhaust holes.

Therefore, the TC-CDS and DD-CDS should be used routinely. These 2 systems can also be disconnected from suction and left on gravity for short periods of time, for example, for patient transfer etc.; however, escape of the SARS-CoV-2 from those systems cannot be entirely excluded.

Also, the DD-CDS' manufacturer advised earlier that this system does not have a viral filter; hence, the usage of this system should be cautious in a suspected or confirmed COVID-19-positive ventilated patient with an air leak.

These results provide an objective validation aimed to help choosing the appropriate CDS and properly manage patients with air leak, without exposing them and healthcare professionals to an increased risk of infection.

The employed simulation model used a novel approach consisting in producing an air leak and demonstrating the amount of aerosolisation through the ultraviolet light. To our knowledge, there are only few studies on this subject in the current literature<sup>18,19</sup> and this is the first simulation of its kind in cardiothoracic surgery. The results of the simulation can potentially apply to many airborne viral infections (influenza A, COVID-19 etc.) to some extent; however, further research in depth is required.

The utilised model has some limitations; namely, the size of the aerosolised particles cannot be reliably determined or quantified and the air flow can vary in the source. The simulation results were produced in the 3 given CDS and may vary in others. The temperature of the fluid was not maintained constant over the experiment time; thereby the amount of steam and finest droplets could be underestimated.

## CONCLUSIONS

In conclusion, patients with an air leak carry potential risks of environmental contamination generating aerosolised particles, and full PPE should be used. According to our study, the SC-CDS is the one generating the largest amount of aerosolised particles and should not be used as an open system in patients with an air leak.

The other systems seem to reduce the number of aerosolised particles irrespective of the air leak entity and fluid volume in the system; therefore they might be disconnected from suction and left on gravity for short periods of time only; however, release of the SARS-CoV-2 from those systems cannot be entirely excluded and use of viral filters in the CDS is recommended.

Patients with prolonged air leak going home with a chest drain might cause contamination of the environment if they

become COVID-19-positive, so community drainage management should be reviewed and readdressed.

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## SUPPLEMENTARY MATERIAL

Scanning this QR code will take you to the article title page to access supplementary information.



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