Review Article

The barrier techniques for airway management in covid-19 patients - review of literature

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Abstract

The coronavirus disease 2019 (COVID-19) has emerged as a pandemic and shall prevail for some time around the globe. The disease can manifest from asymptomatic to severe respiratory compromise requiring airway intervention. Transmission of COVID-19 has been reported to be by droplets, fomites, and aerosols, and airway management is an aerosol-generating procedure. The high viral load in the patient's airway puts the clinician performing intubation at a very high risk of viral load exposure. So, the need for barrier devices was considered and led to reporting of various such devices. All these devices have been reported individually and have not been compared. We present a review of all the information on these devices based on the reported literature.

Keywords: Aerosol, airway, barrier, containment devices, COVID-19, extubation, intubation

Introduction

The coronavirus disease 2019 (COVID-19) was first reported from Wuhan, China in December 2019 and it spread outside China to almost the whole of the world.[1] Since its outbreak in December 2019, the speed and severity of COVID-19 have overwhelmed the healthcare system and its providers.

Transmission of COVID-19

Transmission of COVID-19 has been reported to be by droplets, fomites, and aerosols.[2,3] The clinical spectrum ranges from asymptomatic or mild illness to severe life-threatening complications i.e., acute respiratory distress syndrome (ARDS).[1,4,5] Some of the severe cases require tracheal intubation and invasive ventilation.[6] The health care providers are at constant risk of cross-contamination during the aerosol-generating procedure like laryngoscopy, tracheal intubation, extubation, tracheal suctioning, emergency surgical airway, high flow nasal cannula (HFNC), non-invasive ventilation (NIV), etc.[7,8]

The need for barrier devices

Apart from the personal protection equipment such as face masks, face shields, and eye protection gear, several other techniques and equipment have been reported to restrict the exposure of healthcare workers to aerosols generated during airway management. One such innovation is the barrier device or aerosol box or intubation box [Table 1]. These devices are made up of various materials and have evolved to circumvent the limitations of previous devices [Table 2]. Though these devices have not been evaluated in a robust randomized controlled trial, they appear to have advantages along with some limitations as well. We reviewed the literature published on the use of various barrier devices till 20th January 2021 for airway management in COVID-19 patients.

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Table 1: Barrier Techniques for Airway Management

BOX-RIGID TYPE		SHEET-FLEXIBLE TYPE		HYBRID TYPE	
WITHOUT NEGATIVE PRESSURE	WITH NEGATIVE PRESSURE	WITHOUT NEGATIVE PRESSURE	WITH NEGATIVE PRESSURE	WITHOUT NEGATIVE PRESSURE	WITH NEGATIVE PRESSURE
Aerosol box Modified Aerosol box Modified Neonatal incubator hood 2-piece modification of Barrier box Intubation box, IIT Guwahati	Negative pressure intubation box Thalia intubation box 2.0	Modified double plastic sheets Plastic on bag barrier drape system Three-drape technique Adaptation of plastic barrier sheet	1. Negative pressure barrier tent for extubation	Portable light hood device Covid intubation tent/box Intubation aerosol containment system (IACS)	Vacuum-assisted negative pressure isolation hood (vanish) system Aerosol Containment Enclosure (ACE)

Rigid-box type - without negative suction

Aerosol box

Dr. Hsien Yung Lai introduced a device named aerosol box designed to act as a barrier to contain aerosols.[9] It is a transparent box with 5 sides made of acrylic or polycarbonate sheets to fit over the face and chest of the patient. It has two holes on the same side. Although simple, the design is bulky with limited space and restricts hand movement. There is no provision for an assistant to reach inside and provide airway aids.

Modified aerosol box

Later, a modified version was taller and bigger and with side ports than the original design as released.[10] The design is ergonomically superior as it can accommodate obese patients, allows the use of the ramp, and extra space for airway maneuvering. Also, the top part is sloping to reduce the glare and suitable for short-statured operators. Further, it was modified by the addition of the front lip and base support to prevent it from slipping, if the head end is raised.

Aerosol box 2.0

Aerosol box 2.0 is a lightweight crystalline box with four circular access ports, two for the clinician and two lateral access ports for the assistant.[11] Clips are added to hold the suction device and video laryngoscope. The design is angulated to allow easy accessibility. This updated design is supposed to provide better protection and reduce macroscopic contamination.

Modified neonatal incubator hood

Rahmoune *et al.*,[12] recycled and reused neonatal incubator hood into a barrier device. The portholes provide entry to the hands of the operator, and the side ports can be used by an assistant to perform additional maneuvers. The main drawbacks are heavy design, and its cleaning can be cumbersome.

Two-piece modification of barrier box

To circumvent unanticipated difficult intubation, Chen G *et al.*,[13] suggested dividing the box into two pieces- the top and the bottom for its easy removal. Semi-lunar cuts are scooped out on both halves to make armholes for the operator.

Intubation box-IIT Guwahati

The students of the Indian Institute of Technology (IIT), Guwahati have developed 'low cost intubation boxes' made of transparent acrylic sheets with armholes on one side.[14]

Rigid-box type - with negative suction

Placement of a barrier device solely cannot impart full protection from the aerosols as small droplets remains suspended in the environment. To solve this problem, the provision of negative suction rooms was put forward.[15]

Negative pressure intubation box by Bon Secours St. Francis

The engineering team at the Bon Secours Health Systems facilities has designed a negative pressure acrylic box with two armholes with rubber gaskets.[16] Negative suction is created with a help of vacuum attachment connected to the intubation box via hose pipes with an intervening *High-efficiency particulate air* (*HEPA*) filter.

Thalia intubation box 2.0

Thalia intubation box is the thermo-formed acrylic box with an angled viewing window.[17] It is taller with reduced width and length as compared to the original Thalia box. The box has three arm ports. An additional 7/8 inch vacuum port is added.

Sheet type-without negative suction

The plastic sheet barrier device shields the operator against aerosol spray and imparts protection to the health worker. Other points to be considered are the time required to set up, patients' tolerance to the device, ease of disposal or decontamination of the device after use, and cost and production of the device. The aerosol boxes provide protection but are bulky, time-consuming to set up, and may restrict hand movement. This has led to the development of an economical alternative i.e., sheet-based barrier devices.

Table 2: Description of Various Barrier Devices for Airway Management

	Description	Material	Remarks	Limitations	Disposable/Reusable
			A. RIGID-BOX TYPE-WITHOUT NEGATIVE PRESSURE		
A.1	Aerosol box Dr. Hsien Yung Lai	Acrylic or Polycarbonate	First barrier device 2 armholes	Crowding inside the box Restricted hand movement Heavy built Disinfection No negative suction	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
A.2	Modified aerosol box Malik *et al.*[10]	Acrylic or Polycarbonate	Large size Sloping top part Side port for assistant Front lip and base support	Heavy built Disinfection No negative suction	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
A.3	Aerosol box 2.0[11]	Acrylic or Polycarbonate	Lightweight crystalline box 2 circular access port for clinician 2 lateral ports for passing tools by assistant Clips to hold suction and video laryngoscope Belt to fasten the box on the table	Heavy built Disinfection No negative suction	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
A.4	Modified Neonatal incubator hood Rahmoune *et al.*[12]	Plexi-glass	One side removed and the base strengthened Robust design and more space Side ports for assistant	Heavy built Disinfection No negative suction	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
A.5	Two-piece modification of Barrier box Chen G *et al.* [13]	Plexi-glass	Horizontally divided into two parts (removable upper part) Side port for assistant	Heavy built Disinfection No negative suction	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
A.6	Intubation box IIT Guwahati[14]	Acrylic or Polycarbonate	Inspired by the original aerosol box	Heavy built Disinfection No negative suction Inadequate seal	Reusable Wipe the inner surface with standard disinfectant
			B. RIGID-BOX TYPE-WITH NEGATIVE PRESSURE		
B.1	Negative pressure intubation box Bon secours st. Francis[16]	Acrylic	Acrylic box with two arm ports 2 armholes with rubber gaskets Negative suction attached with a hose with a HEPA filter	Heavy built Disinfection No arm port for assistant	Reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution)
B.2	Thalia intubation box 2.0 Thaliacapos[17]	Thermoformed acrylic box	Increased height, decreased width, and length Sloping top part 3 arm ports (1 for assistant) and 1 vacuum port Glad Cling Wrap to seal the hand holes	Heavy built Disinfection	Partially reusable A new Glad cling wrap to be used for the next patient
			C. FLEXIBLE-SHEET TYPE- WITHOUT NEGATIVE PRESSURE		
C.1	Modified double plastic sheets Brown *et al.*[19]	Double plastic drapes (120*100 cm) with 12-15 cm facial opening and two 7 cm lateral cuts for operators hand	Minimal hand restriction	Less vertical space Patient discomfort	Disposable
C.2	Plastic on bag barrier drape system Brown *et al.*[19]	One 40 gallon drawstring bag and a clear rectangular plastic sheet (90×95 cm).	Minimal hand restriction	Less vertical space Patient discomfort	Disposable
C.3	Three-drape technique Matava *et al.*[20]	Three clear plastic sheets	Minimal hand restriction	Less vertical space Patient discomfort	Disposable
C.4	Adaptation of plastic barrier sheet Yang *et al.*[21]	Plastic sheet with two cross cuts of size 3×3 cm and 2×2 cm	The plastic sheet allows airway maneuvers from over the sheet Minimal hand restriction	Less vertical space Patient discomfort Less robust design	Disposable
C.5	Extubation barrier drape Patino Montoya *et al.*[22]	A large 137×229 cm clear plastic sheet with a 1-2 cm slit	To be used during extubation Contain droplets if the patient coughs during extubation	Less vertical space Patient discomfort Only for extubation	Disposable

Contd...

Table 2: Contd...

	Description	Material	Remarks	Limitations	Disposable/Reusable
			D. FLEXIBLE-SHEET TYPE- WITH NEGATIVE PRESSURE		
D.1	Negative pressure barrier tent for extubation Hung *et al.*[23]	Plastic sheet split open to form a tent	Continuous negative suction applied at the filter connector sucks out the aerosols	Less vertical space Patient discomfort Less robust design Designed for extubation only	Disposable
			E. HYBRID TYPE-WITHOUT NEGATIVE PRESSURE		
E.1	Portable light hood device Kangas-dick *et al.*[24]	PVC framework covered with semi-transparent nylon sheets	Minimal hand restriction Lightweight	Disinfection	Partially reusable PVC framework wiped with standard sani-cloth, contaminated plastic sheets to be replaced after each use
E.2	Covid intubation tent/box Henneman, Your Design Medical[25]	The L-shaped framework of PVC pipes covered with a clear Vinyl sheet forming a pyramid-shaped hood	Minimal hand restriction Lightweight Short building time Easily available raw material Armholes can be cut out	Disinfection	Partially reusable PVC framework wiped with standard sani-cloth, contaminated plastic sheets to be replaced after each use
E.3	Intubation aerosol containment system (IACS) Gore *et al.*[26]	Polycarbonate barrier (PCB) and a transparent plastic drape attached to upper and lateral edges of PCB	Minimal hand restriction Lightweight 2 armholes with easy accessibility for assistant Sloping PCB sheet for better visualization	Disinfection	Partially reusable PCB barrier to be wiped clean with standard disinfectant and replace plastic sheet after each use
E.4	Patient Particle Containment Chamber (PPCC)	Standard shower liner draped over a modified octagonal PVC pipe frame and secured with binder clips	Minimal hand restriction Lightweight Easily available raw material	Disinfection	Partially reusable PVC framework wiped with standard sani-cloth, contaminated plastic sheets to be replaced after each use
			F. HYBRID TYPE-WITH NEGATIVE PRESSURE		
F.1	Vacuum-assisted negative pressure isolation hood (VANISH) system Convissar *et al.*[28]	The L-shaped framework of PVC pipes covered with a clear vinyl sheet with a Stryker Neptune™ high-powered suction system	Better air exchange as compares to wall suction Mobile device No need to replace the in-line Stryker Neptune HEPA filter for every patient	Costly Availability of Stryker Neptune™ suction system Disinfection	Partially reusable PVC framework wiped with standard sani-cloth, contaminated plastic sheets to be replaced after each use
F.2	Aerosol Containment Enclosure (ACE) Chahal *et al.*[31]	Silicon gasket with polyethylene sheet covering the whole of the patient	Large size Sloping roof 4 arm ports for clinician and assistant Ports for attaching 2 wall suction	Prone to cracking on impact and may shatter when dropped from a height or with a severely agitated patient Disinfection	Partially reusable Wipe the inner surface with standard disinfectant (like hypochlorite solution), contaminated plastic sheets to be replaced after each use
F.3	COVID-19 Airway Management Isolation Chamber (CAMIC) system Blood *et al.*[32]	Polyvinyl chloride hollow frame with fenestrations, covered with a clear surgical bag. There is a port for suction and oxygen delivery	Resilient barrier Safe for both invasive and non-invasive airway management Readily available raw material	Disinfection	Partially reusable PCB barrier to be wiped clean with standard disinfectant and replace plastic sheet after each use

Modified double plastic sheets

Ibrahim *et al.*,[18] described the use of double plastic drapes made up of disposable bags. Improvised double sheets can be made by making a 12-15 cm radius facial opening on the lower layer of the disposable plastic sheet. Two 7 cm long openings are made on the lateral side of the upper layer to allow passage of clinicians' hands to perform airway maneuvers. The proximal ends of the sheets are sealed and taped to the procedure table and the distal ends are taped at the patient's chest. Due to the flexibility of the plastic sheets, the restriction of hand around the armholes is less as compared to rigid boxes. Modified double plastic sheets provide almost equivalent protection as compared to modified aerosol boxes.[17]

Plastic on bag barrier drape system

Another modification of plastic clear sheets is proposed by Brown *et al.*,[19] This plastic on bag barrier drape system requires a 40 gallons drawstring bag and a clear rectangular plastic sheet. The drawstring bag covers the head end of the patients' table. Another rectangular plastic sheet is taped at the chest level and rolled over the patient's head including the anesthesiologist's hands underneath. To tighten the sheet downwards, a clamp was attached to it. In the end, the patient can be extubated in between the sheets and sheet along all disposables are rolled on a drawstring bag and disposed.

Three-drape technique

Aerosols and the droplets generated during the procedure can settle on any surface and act as a source of contamination. Matava *et al.*,[20] suggested a low-cost three-drape technique where three clear plastic drapes, first one is placed below the patient's head over the procedure table, the second covers the torso from the neck down, and the third covers the patient's head from mid sternum level to prevent spillage to the surrounding areas.

Adaptation of plastic barrier sheet

Yang YL *et al.*,[21] have put forward a simple innovative idea to use a plastic sheet with two cross cuts (X) across the drape reinforced using tape. First 'X' is to pass the anesthesia breathing circuit and the smaller second cut is to allow passage of video laryngoscope, endotracheal tube, or suction tip.

Extubation barrier drape

Extubation barrier drape comprises of a large clear plastic drape (137 × 229 cm) with a small 1-2 cm slit.[22] The assembly is placed around the tracheal tube and sealed with tape before extubation. When the patient is extubated, the drape will contain all the aerosols generated during the extubation. In the end, the drape can be discarded along with the tracheal tube.

Sheet type-with negative suction

Negative pressure barrier tent for Extubation

During tracheal intubation, the patient is paralyzed and if the adequate depth is maintained, the degree of aerosolization can be drastically reduced. Whereas, during extubation the patient is awake and there is a high probability of coughing and aerosol generation. A simple technique has been suggested by Hung *et al.*,[23] to be used during extubation. It comprises a tent made up of clear plastic sheet and negative suction. The plastic bag is split from one side and placed over the patient like a tent with an apical hole. The bag is secured with tape around the endotracheal tube to create a tight seal. The whole arrangement is such that the patient with the distal end of the endotracheal tube lies within the tent and the ventilatory circuit with the proximal end lies outside the tent. While pulling out the endotracheal tube the plastic tent is gently lifted creating a negative suction inside the tent. The aerosols generated are removed via endotracheal tube tip and into the attached filter. A simulated study has also demonstrated suspended drifting of the droplet nuclei towards the endotracheal tube tip inside the tent. Thus, this negative pressure barrier tent has the potential to contain large as well as smaller aerosols.

Hybrid type-without negative suction

The rigid-box type barrier devices are made up of plexiglass which is bulky and difficult to transport. The decontamination of boxes is often cumbersome. To overcome this issue, a hybrid device with qualities of both rigid box and the flexible sheet was invented.

Portable light hood device

A portable light hood device, a type of hybrid barrier device comprised of a light-weighted PVC framework covered with semi-transparent nylon sheets on four sides with two sides uncovered.[24] The uncovered sides allow the hood to be placed over the chest for airway management. After use, the contaminated nylon sheets can be disposed-off.

COVID intubation tent/box

Another barrier device in the list is the COVID tent/box put forward by 'Your Design Medical'.[25] Its design is based on two principles- negative pressure and directional shielding. It comprises of 'L' shaped framework made up of 6 ½ inch PVC pipes of length 23.5 inches each. PVC pipes are put together with the help of four 3-way and curved standard fittings at junctions. The whole framework is then covered with a clear vinyl sheet forming a pyramid-shaped hood. The sheet can be cut out within seconds to make way for the clinician's and assistant's hands. Overhead arms 6 inches long can be added on the top braces, this prevents the sheets from falling over the patient creating additional space.

Intubation aerosol containment system (IACS)

IACS comprises of two parts, a polycarbonate barrier (PCB) with two circular arm ports and a transparent plastic drape attached to the upper and lateral edges of PCB.[26] The sheet extends up to the chest and lower limbs of the patient. The front side is slanting downwards, and the upper portion is tapered towards the patient to allow an optimal view of the patient. IACS was tested with a commercial fog machine, no escape of mist was noticed.

Patient Particle Containment Chamber (PPCC)

It has a modified octagonal PVC pipe framed structure with shower liner drape secured with binder clips with a weighted tube to contour the patient.[27] The simulation experiment demonstrated that PPC can contain 99% of the spray paint particles sprayed over 90 secs.

Hybrid type-with negative suction

Vacuum-assisted negative pressure isolation hood (VANISH) system

A mobile and readily available Stryker Neptune™ (Stryker Corporation, Kalamazoo, Michigan) high-powered suction system is added to the conventional design to create a negative pressure biohazard isolation environment.[28] As compared to the wall suctions, the Stryker Neptune generates greater suction with better air exchange.[29,30] Moreover, the in-line Stryker Neptune HEPA filter can be used in multiple patients and need not be replaced for each new patient.

Aerosol containment enclosure (ACE)

Aerosol containment enclosure (ACE) is a combination of modified intubation box with a provision for negative suction.[31] It comprises a silicone gasket with arm ports for the main operator and an assistant. The size of the gasket is wide enough to suit a wide range of patients. The roof is sloping to prevent glaring and ensure optimal visualization. Arm ports are wider, and a silicon gasket is added to improve the seal around the arms. A high-density polyethylene sheet extends from the gasket to cover the whole of the patient. There is a provision to generate negative pressure using two hospitals' suctions. ACE with negative pressure has been shown to contain airborne particles in a simulation study.[31]

COVID-19 Airway Management Isolation Chamber (CAMIC) system

CAMIC[32] comprises of polyvinyl chloride hollow frame with fenestrations, covered with a clear surgical bag. There are an internal suction and oxygen delivery system that creates laminar flow and facilitates evacuation of droplets. Preliminary tests have demonstrated the removal of >99% of smoke and nebulized saline particles with the minimal leak. It can also be used during non-invasive airway management like high flow oxygen, nebulization, continuous positive airway pressure ventilation.

Evidence for aerosol containment boxes in clinical practice

The majority of the barrier devices invented are plastic drape type (59%) and the rest are box type (42%).[33] Due to time constraints, to date, no large-scale randomized control trial has been conducted to provide solid evidence in support of these devices. The majority of the recommendations are based primarily on the visual assessment of aerosol and droplet spread. Experiments simulating cough in a mannequin have been conducted to check their efficacy. Box type was the first barrier device described but is often associated with the delay in time to intubation and worsening of laryngoscopic views. On the other hand, the plastic sheet system apart from being simplistic has demonstrated better efficacy and usability so far.[33]

Canelli *et al.*,[34] conducted a simulation study mimicking cough, using a fluorescent dye (10 mL) filled latex balloon placed at the hypopharynx of the mannequin. They reported that when an aerosol box was used, the dye was observed only inside the box, gloves, and gown of the clinician. Although, the box restricts hand mobility and makes the use of additional aids difficult.

To determine the efficacy and superiority over the previously described aerosol boxes, Ibrahim *et al.*,[18] performed a simulation using a tracheal tube cuff balloon filled with 30 mL fluorescent dye. The balloon was inflated till it burst, simulating a cough. The experiment was performed in 4 settings: with PPE only, with aerosol box, modified aerosol box, and modified double plastic drapes. Both modified aerosol boxes and modified double plastic sheets provided good protection in this mannequin study but one must be aware of its limitations and use it only as an adjunct to PPE methods.

Another simulation study on pediatric mannequin covered with single clear plastic drape, three drapes technique and without any barrier technique was performed using 0.5 mL of fluorescent resin powder. The degree of aerosolization was reduced with a single drape technique but the maximum reduction was demonstrated using the three-drape technique.

Chahal *et al.*,[31] evaluated protective capability and differential pressures generated in aerosol containment enclosure (ACE) with negative pressure. Authors observed that the device could contain smoke, fluorescein, and sodium saccharine aerosol in all the experimental settings as compared to identical barrier devices with non-occluded ports and ambient pressures.

An *in-situ* simulation cross-over study to evaluate the impact of two aerosol boxes (an early-generation and a latest-generation box) on intubation in patients.[35] Intubation time without the box was found to be significantly shorter as compared to use of any of the boxes. It was stated that aerosol boxes can increase intubation time and may expose patients to the risk of hypoxia. In one case breach of PPE was also noted.

Since the introduction of the aerosol box, there has been a race to develop more innovative equipment, although none of them have been tested in ideal patient conditions. Some of them were tested by simulating cough in a mannequin but the method of simulation cannot be considered ideal. Considering the limitation of previous simulation models, another attempt was made by Simpson *et al.*,[36] with more standardized equipment. The authors used Hudson RCI "Micro Mist" small volume nebulizer (Teleflex, Wayne, PN, USA) without facemask and generated aerosols of size 0.3-5.0 micron by nebulization of 5 mL saline at 6 L/min flow. The authors reported that the sealed intubation box decreases the spread of 0.3 to 2.5-micron particles as compared to a setup with no device. No difference was noted between no device, horizontal drape, and vertical drape setups. Finally, a significant increase in airborne particle exposure was noted when the patient coughed within an aerosol box as compared to other devices or no device. This is supported by a simulation study of Dalli *et al.*,[37] which demonstrated that there is a substantial escape of contaminated air from armholes, especially during coughing. The sealed box with suction was able to demonstrate adequate protection, but only if continuous suction is applied.

Fried *et al.*,[38] simulated coughs in both box and sheet type intubation boxes. It was inferred that both types can contain droplets during simulated coughs but redirect aerosolized particles towards the foot end.

Considering the lack of resources, a hybrid barrier device with negative suction that can be partially reused with easy decontamination can be appropriate for the Indian resource-limited setting. But we must always emphasize the use of other personal protective equipment along with proper hand hygiene.[39]

The aerosol generation under regional techniques

Patients undergoing surgery under regional anesthesia also possess the risk to health care workers. The use of the triple-layer mask is an accepted norm for patients. Even in cases, where oxygen supplementation is required, a triple-layered surgical mask should be worn over the oxygen delivery device.

Conclusion

There is an urgent need for testing these devices in real-time clinical settings. It must be kept in mind that these kinds of devices cannot replace existing PPE precautions; rather they can be used as an additional aid to PPE. The use of such boxes must never compromise a patient safety or complicate the procedure. There is very limited data supporting such barrier devices, and we must embrace such innovations with caution.

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Conflicts of interest

There are no conflicts of interest.

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