



# The efficacy of an aerosol box to prevent infections during aerosol-generating procedures

Učinkovitost aerosolne škatle za preprečevanje okužb pri posegih, pri katerih nastajajo aerosoli

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## Abstract

The new risks faced by healthcare workers in the COVID-19 pandemic have inspired the development of new forms of personal protective equipment (PPE). Such a novel PPE is an aerosol box modified and adapted to facilitate safer intubation of patients infected with SARS-CoV2. Hitherto, the idea of a protective aerosol box has found clinical application in anaesthesiology and many other fields of medicine and dentistry. However, numerous criticisms of the original design have led to the evolution of new forms that gradually improved the original shortcomings. The present modified design improves the safety and simplicity of use while reducing the operator's hindrance during interventions. Operator training is also extremely important for the correct and safe use of the aerosol box in clinical practice. Aerosol box does significantly affect the speed of intubation therefore it is not recommended in urgent cases. Many authors have been able to prove that the use of the original box, as well as its later modifications, adequately protects healthcare workers from large and small water droplets. However, the use of the original form increases the risk of infection with aerosol particles.

## Izvleček

Izpostavljenost okužbi zdravstvenih delavcev zaradi pandemije covid-19 je privedla do razvoja novih oblik osebne varovalne opreme. Ena od njih je aerosolna škatla, ki je bila zasnovana z idejo, kako varneje vstaviti dihalno cevko v sapnik bolnikom, okuženim z virusom SARS-CoV2. Uporaba aerosolne škatle ne sega samo v področje anesteziologije, ampak tudi v druga področja medicine. Številne kritike na račun prvotne zasnove so vodile v izdelavo novih oblik, ki postopoma izboljšujejo prvotne pomanjkljivosti. Razvoj se usmerja predvsem v okoliščino, kako zmanjšati oviranost kirurga (ali izvajalca) pri posegih ter kako zagotoviti varnejšo, enostavnejšo in hitrejšo možnost uporabe. Številnim avtorjem je uspelo pokazati, da uporaba aerosolne škatle pomembno vpliva na hitrost vstavitve dihalne cevke v sapnik, zato v urgentnih

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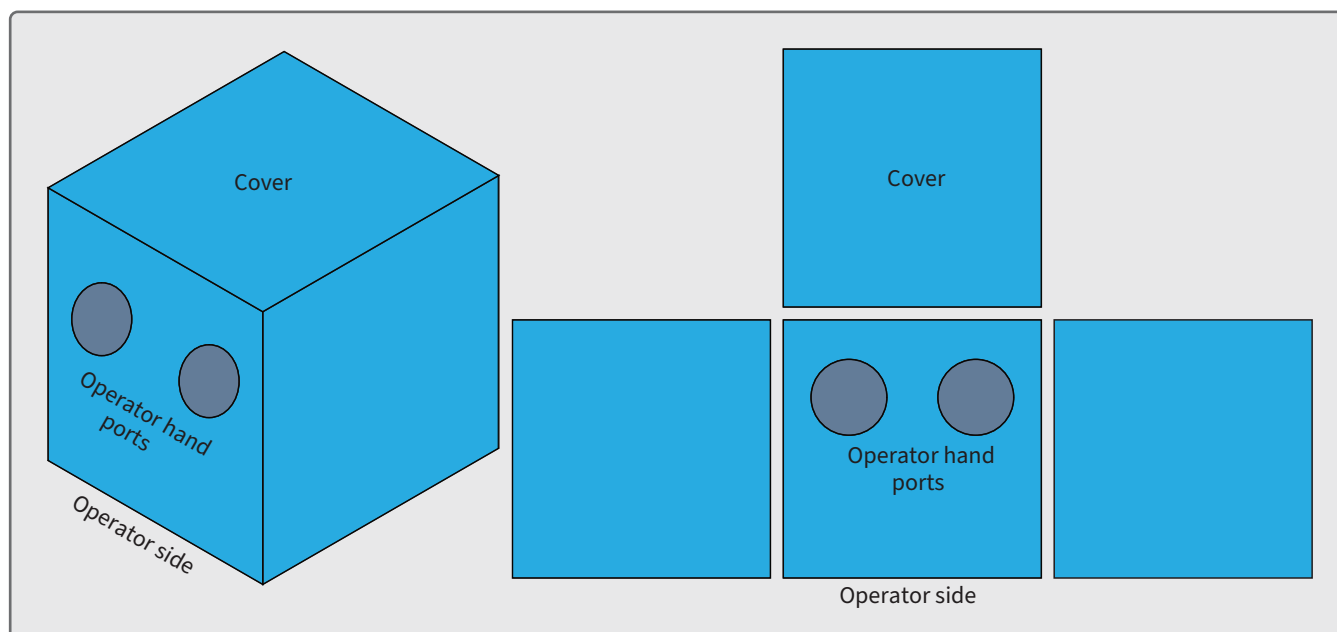
primerih odsvetujejo uporabo aerosolne škatle. Ob primerni uporabi ter ustreznem urjenju zdravstvenega delavca pa se je izkazala kot učinkovita osebna varovalna oprema, ker zdravstvene delavce dobro zaščiti pred velikimi in majhnimi vodnimi kapljicami. Pravilno posodobljena oblika aerosolne škatle dobro varuje tudi pred aerosolnimi delci, medtem ko uporaba izvirne oblike lahko tveganje za okužbo zdravstvenega delavca z aerosolnimi delci še poveča.

## 1 Introduction

The COVID-19 pandemic posed an additional risk to healthcare workers, exacerbated by a possible lack of personal protective equipment (PPE). SARS-CoV-2 is spread mostly via droplets from the upper respiratory tract, but aerosol transmission is also possible (1). The particles with which the virus is transmitted are of different sizes and can be defined as large droplets with a diameter of 60  $\mu\text{m}$  and more, small droplets with a size of 10 - 60  $\mu\text{m}$ , and aerosols, particles that are smaller than 5  $\mu\text{m}$ . Large droplets can reach surfaces up to two metres away, small water droplets reach distances even greater than two meters, and aerosols can remain airborne for three hours after formation (2-4). Therefore, protection during aerosol-generating procedures is crucial as healthcare workers performing these procedures are at increased risk from infection (1,3,4). Other measures, such as reducing the number of staff in the area where interventions are carried out, sterilization and disinfection of equipment and PPE use are also effective in reducing aerosol transfer (4,5). Endotracheal intubation and extubation, non-invasive ventilation, tracheotomy, oropharyngeal/tracheal aspiration, bronchoscopy, oesophagogastrroduodenoscopy, transoesophageal echocardiography and surgery in the head and neck area are counted among the aerosol generating procedures (AGP) (3,6). The World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) have defined the lists of procedures for which PPE use is mandated, consisting of a hair cover, protective goggles, N95 mask, gloves and a gown with long sleeves (7-9). High levels of workload and limited access to technology and materials for patient care encourage the development of strategies to improve personal protection in countries with less developed health systems (10). In the latter, the risk of aerosol transfer is increased due to a number of additional risk factors, such as inadequate ventilation, performing procedures in rooms where negative pressure cannot be established, lack of rooms to prepare for procedures, hospital rooms with multiple patients and inadequate sealing of doors and windows (4,11-14). Due to an increased risk of infection during AGP, forms of

PPE have been developed during the COVID-19 pandemic, the aerosol box among them. It is a transparent box made of acrylic or polycarbonate, which covers the patient's head and has two ports that allow the operator to access the airway, handle devices and allows for endotracheal intubation or extubation (15). The first design for the box was published in March 2020 by the Taiwanese anaesthesiologist Lai Hy with the purpose of safer endotracheal intubation. The original aerosol boxes were designed as transparent boxes measuring 50 x 50 x 40 cm with two circular ports 10 cm in diameter for the operator's hands (Figure 1). The original design sought to maximize reusability. It used materials that are resistant to higher temperatures, and its price was estimated at \$67 for one aerosol box (1,16-20). Transparent acrylic or polycarbonate panels, 5-6 mm thick, were most often used to make the aerosol box, while newer aerosol boxes also use thicker acrylic, up to 9.5 mm thick, or thinner acrylic, 3 mm thick, a large difference in final weight (17,20-24). The advantages of acrylic material are permanent transparency, free and wide availability and low price. It is also easy to cut and bend at higher temperatures (25). The quality of the original model has deteriorated in some places after only three to five uses, while the version with thicker acrylic allows up to eight weeks of intensive clinical use and numerous disinfections (17). The time to make an aerosol box is estimated at four hours and the setup time for clinical use is 5-7 minutes (24,26).

Numerous criticisms of the original aerosol box design and the increase in infections among healthcare professionals during a general PPE shortage have spurred the rapid development of the original aerosol box, which has undergone many improvements (22). The usefulness of the aerosol box is not limited to interventions to provide a patent airway, but also extends to other areas of medicine. To date, the possibility of its use has also been described in the field of (a) dermatology for facial procedures, (b) ophthalmology for surgery, (c) gastrointestinal surgery for emergency surgery, (c) gastroenterology for oesophagogastrroduodenoscopy, and (d) neonatology for AGP of neonates



**Figure 1:** Aerosol box.

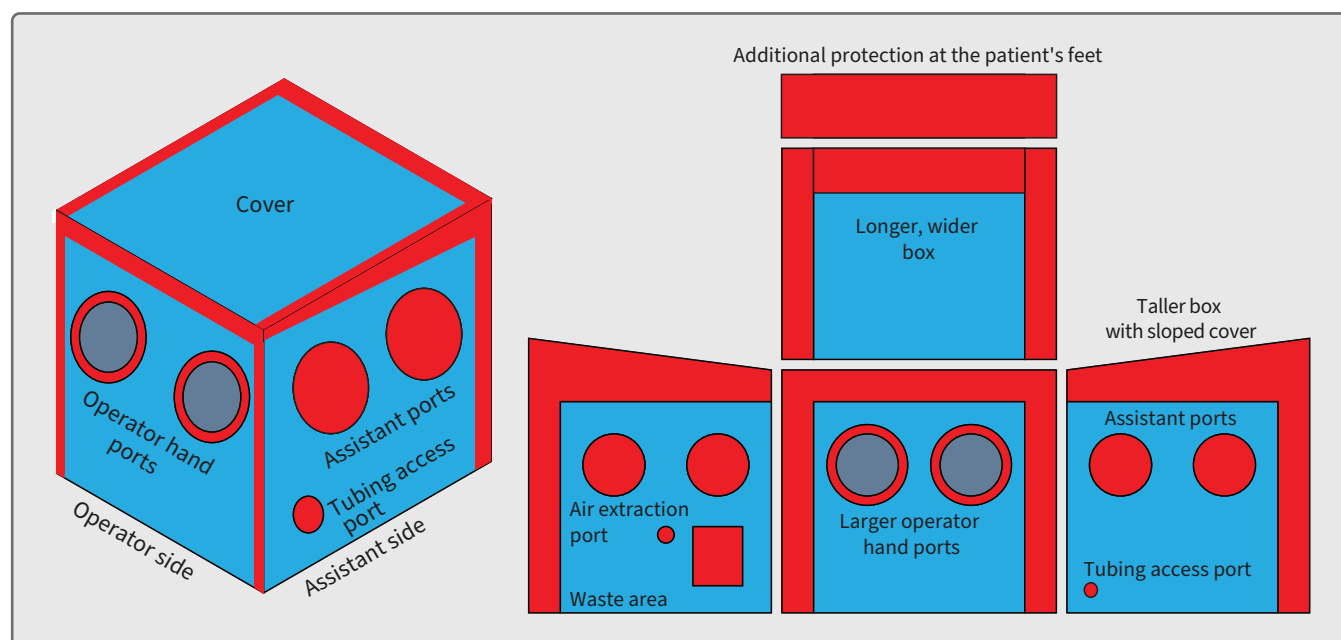
The original design of the aerosol box has six sides. The upper and lateral sides are without ports; the operator side has two hand ports; the feet-facing side and lower side are open. The centre of the port is 25 cm removed from the lower border and 10 cm from the lateral border of the aerosol box, per Lai HY, 2020 (20).

whose mothers are infected with SARS-CoV2 virus. The authors also mention the use in dentistry and otorhinolaryngology (3,7,23,24,26-30).

## 2 Drawbacks of the original aerosol box design

The simple design of the original aerosol box has been frequently criticized, so many researchers are trying to address these shortcomings. First and foremost, the aerosol box has been shown to complicate vital procedures that need to be carried out extremely quickly, making it less useful for emergencies (31). The prolonged set up time can significantly prolong the time to the emergency procedure's start, and at the same time further impede the operator's access to the patient (24,26,32). The two most common subjective problems with handling an aerosol box are discomfort with handling the bougie and laryngoscope and mentally taxing the operator, which has often led to the abandonment of aerosol box use in many hospitals (1). In addition to the shortcomings already mentioned, there are often problems due to: (a) inadequate size, especially in overweight and short-necked patients (18,32); (b) insufficient aerosol box height, which does not allow proper

handling of the elastic bougie, making the procedure more difficult, particularly for operators of lower stature, and (1,22,32); (c) too small or excessive diameter of the hand ports or the absence of the ports for nurse's assistance (1,24). The original design of the aerosol box has also received considerable criticism for: (d) inadequate design of the panel facing the patient's feet, as this does not protect staff located near the open panel (8,17,33,34); (e) the lower part, which tends to slide and requires the assistance of staff in stabilizing the aerosol box (27,28); (f) the inability to safely and quickly remove the box in case of airway problems (22,32); (g) the inability to maintain negative air flow and prevent the air and aerosols from escaping (7,26); (h) heavy weight and rigidity in handling; (i) short lifespan and (j) problems with storage and cleaning (17,33,35). Opinions about cleaning and disinfecting the aerosol box differ greatly. Some cite the ease of disinfection as an advantage, while others cite the difficulty of disinfection as one of its main drawbacks (21,31). A 70% alcohol solution is recommended for disinfection, which can be replaced by a 0.5% hypochlorite solution (20,21,28). Due to the alleged shortcomings, there have been a number of updates and improvements to the boxes, which try to eliminate errors and increase their usability.



**Figure 2:** Frequent updates to the original aerosol box.

### 3 Improvements to the original aerosol box design

Several improvements to the aerosol box have already been proposed in an attempt to address the shortcomings of the original design (Figure 2). The most common update is the added side port or more ports that make it easier to give and use instruments (1,7,16,28,32). The ports are normally circular, 10–12.5 cm in diameter, but can also be square in shape, up to 27 x 27 cm in size (3). They are commonly free to open, but can be covered with removable acrylic material, neoprene or nitrile rubber, which can be discarded after use (2,10,20,32,36). Frequently, an air outlet is added (1,27). A polypropylene drape covering the chest can be attached to the surface facing the legs; the side surfaces of the aerosol box may be tilted upwards towards the operator. Due to the different patient sizes, the width and curvature of the lateral surfaces can be adjusted, allowing easier access to patients with higher body weight and wider shoulders. Frequent updates also include the increased aerosol box height, which makes it easier to handle instruments, and the changed inclination of the upper surface with an angle between 8° and 30°, which allows a more comfortable position for the operator and less difficulty handling bougies, laryngoscopes and other longer instruments. The slope can cover the entire upper side or only part of it. A belt can also be added to stabilize the aerosol box and reduce the need for additional stabilization during procedures (10,22,27,28,32,37–39) (Table 1).

To facilitate handling of the aerosol box, plastic spacers may be added on its upper surface to allow easier storage when the box is not in use; side handles for quick removal in emergencies; staples holding the suction device and laryngoscope; and a waste bag (10,22). Some aerosol boxes are also foldable to take up less space when not in use (35,38). The specially designed KS-type acrylic aerosol box (Kojima/Sugimura) also allows more freedom in handling instruments. It is similar in design to the original aerosol box, but without sides next to the operator. A transparent plastic cover is required for installation, into which ports are cut with scissors before use, and the operator's hands are wrapped with adhesive tape to additionally seal the opening (40). Table 1 summarizes the main features of some updated aerosol boxes. Other forms of protective equipment have also been described as a substitute for the aerosol box, e.g. single-use drapes in the form of a tent (33).

### 4 The effect of the aerosol box on the speed and success of endotracheal intubation

PPE should not endanger the safety of the patient or staff (22), but at the same time it should enable quick access to the patient in case their vital functions rapidly worsen (37). Several studies have evaluated the impact of an aerosol box on the speed and success of endotracheal intubation (Table 2). The results uniformly show that the use of an aerosol box in its original or

**Table 1:** Comparison of the original aerosol box design with updated designs (10,20,21,24,26,27,38,39).

	Size (cm)	Material	Shape	Access ports	Feet-facing side	Air extraction system	AC risk
Original aerosol box (20)	40 x 50 x 50	TA	<b>rectangular</b>	<b>2 ports:</b> 2 OP	open	NO	<b>high</b>
Aerosol box with negative air flow (26)	43 x 53 x 53	TA	<b>rectangular – upper side ND</b>	<b>6 ports:</b> 2 OP, 4 LS	slosed with <b>synthetic material</b>	YES	<b>low</b>
Aerosol box for dentistry (27)	50 x 60 x 60	ND	<b>rectangular – upper side ND, lower side SU</b>	<b>4 ports:</b> 2 OP, 2 LS	open	NO	ND
Neobox – box for neonates (24)	42 x 42 x 56	TP	<b>rectangular – upper side ND</b>	<b>6 ports:</b> 2 OP, 4 LS	open or <b>PE</b>	NO	ND
Aerosol box 2.0 (10)	NP	TA, nitrile rubber	<b>rectangular – upper side ND</b>	<b>4 ports:</b> 2 OP, 2 LS	covered with <b>plastic drape</b>	YES	ND
SLACC – suction-assisted local aerosol containment chamber (39)	NP	NP	<b>Irregular hexagonal</b>	<b>5 ports:</b> 2 OP, 2 LS, 1 T	covered with <b>plastic drape</b>	YES	<b>low</b>
Aerosol box Serdinšek et al. (38)	NP	TA, aluminium, neoprene	<b>rectangular</b>	<b>4 ports:</b> 2 OP, 2 LS	<b>PP drape</b>	YES	ND
»Endoprotector« box (21)	40 x 45 x 50	TA	<b>rectangular</b>	<b>3 ports:</b> 2 OP, 1 LS	open	YES	ND

Legend: AC – aerosol contamination; SU – sloped upwards in the direction of the operator; SD – sloped upwards in the direction of the operator; ND – no data; OP – for the operator; PE – polyethylene; PP – polypropylene; LS – on the lateral side; TA – transparent acrylic; TP – transparent polycarbonate; T – on the top.

updated form affects the endotracheal intubation speed (1,19,37,38,41). Begley et al. have found that the endotracheal intubation time is lengthened by 38.3 second with the use of the original aerosol box design and 9.3 seconds with the updated design (19). The other authors cite values between the previous ones (37,38,41-44). A meta-analysis by Lim et al. summarized that the endotracheal intubation time is significantly lengthened (>4 seconds) with the use of an aerosol box (43). When analyzing studies, it should be borne in mind that these have been simulated and do not account for all the factors that occur in real circumstances, so the time may actually be even longer. Factors such as lack of experience, operator's mental overload, procedural problems and reduced visibility can further prolong the endotracheal intubation time, which is particularly important in critically ill patients with severe COVID-19 who have significantly reduced tolerance to lack of

oxygen (1,43-46). Trujillo et al. have noted that the use of an aerosol box significantly lengthens the endotracheal intubation time in infants and children (47). Researchers have also found that the aerosol box has less effect on the endotracheal intubation time when using the videolaryngoscope when compared to the laryngoscope (38,41). Most authors also did not find differences in the first attempt at endotracheal intubation with or without the use of an aerosol box. Nevertheless, some authors reported up to 6% lower success rate at the first attempt at endotracheal intubation with the use of an aerosol box (1,19,37,38,41,46,48).

Opinions about the use of an aerosol box during intubation in clinical practice are divided. Numerous authors recommend their use (19,35,37,41,47), but Malik et al. advise against the use of the original aerosol box in emergency intubation due to reduced manoeuvrability, which can affect the intubation speed. They mention a

**Table 2:** The effect of the aerosol box on the speed and success of endotracheal intubation (1,19,37,38,44).

Study	Begley et al. (1)	Clariot et al. (37)	Serdinšek et al. (38)	Wakabayashi et al. (19)	Turner et al. (44)
Number of endotracheal intubations	36	94	144	108	96
Number of operators	12	47	36	18	48
AB	Original and modified AB (upper and lateral port)	Modified AB (upper side sloped forward)	Modified AB (Table 1)	Original AB	Original AB
Time to successful endotracheal intubation without AB	42.9 s DL	48 s DL	23 s DL 25 s VL	14 s DL 14 s VL	12.2 s VL
Lengthening of time required for endotracheal intubation	+38 s AB +9 s mAB	+5 s DL	+4 s DL +9 s VL	+3 s DL +1 s VL	+8.4 s VL
Success rate of first attempt at endotracheal intubation	100% without AB 75% AB 83% mAB	100%	95.4% without AB 94.4% mAB	100% without AB 100% AB	ND

Legenda: AB – aerosol box; mAB – modified aerosol box; DL – direct laryngoscopy; ND – no data; VL – videolaryngoscopy; s – second.

number of procedures when the patient's safety is not endangered as much, thus allowing for the use of an aerosol box – e. g. tracheal extubation, nasogastric tube insertion, tracheal tube exchange and patient transfers (22). It can be summarized that the time of endotracheal intubation is significantly lengthened with the use of an aerosol box, so its use is not recommended in emergencies. We must also be aware that the aerosol box is an additional physical barrier that affects the way interventions and procedures, which the operator is already experienced with, are performed.

## 5 Aerosol box safety

The risk of introducing new equipment or protocol must always be balanced by proven effectiveness. The procedure must protect the provider and other healthcare staff and be safe for the patient at the same time (49). To confirm the protective function of the box, several studies have shown that the use of an upgraded aerosol box with an active air extraction system can effectively reduce contamination of the operator and assistant with both large and small water droplets. At the end of the procedure, the aerosol box and the contents of the box remain contaminated, which can lead

to additional infections if not handled properly and disinfected (4,5). It is important to be aware that transmission can also occur after the procedure, especially during the removal of the aerosol box (48). Serdinšek et al. have shown that when the hands contaminated with large droplets are removed from an aerosol box with neoprene covered ports, the outside of the box remains uncontaminated (38). All the research published so far, which studied the contamination with water droplets, showed a significant reduction in the operator's and environment's contamination when using an aerosol box (Table 3) (8,21,50,51). Fried et al. also showed the importance the patient's position plays during endotracheal intubation, which also affects the healthcare worker's exposure. The latter is lowest at the slight reverse Trendelenburg position, which, however, is not optimal for direct laryngoscopy (51).

Numerous studies have confirmed that the use of an aerosol box limits the macroscopic contamination of the operator; however, concerns about aerosol exposure remain (34). With dynamic analysis of air flow, Dallin et al. showed increased air leakage during deep breathing and coughing with the original aerosol box. The completely open surface facing the patient's legs is particularly exposed. When using the drape, the air does

**Table 3:** Studies comparing droplet contamination with or without an aerosol box (8,21,50).

Study	Aerosol box	Study description	The result with an aerosol box	The result without an aerosol box
Canelli et al. (50)	Original aerosol box	The operator was in the standard position for endotracheal intubation. <b>A cough was simulated with balloon cuff rupture.</b> A <b>balloon cuff</b> with 10 mL of <b>fluorescent fluid</b> was inserted in <b>the manikin's hypopharynx</b> and inflated with <b>oxygen</b> until it <b>burst</b> . This simulated a cough, neglecting the direction, speed and turbulence of a real cough.	Only <b>the inside of the box</b> , including <b>the operator's gloves and forearms</b> , was <b>contaminated</b> . Macroscopic contamination outside the aerosol box was not observed.	<b>The gloves, clothes, face mask, glasses, hair, neck, ears and shoes of the operator</b> were <b>contaminated</b> . The <b>floor</b> was contaminated within a radius of one metre, and a <b>monitor</b> two metres away was also contaminated.
Campos et al. (21)	Modified aerosol box – endoprotector	The operator was in the same position as in the previous study. The assistant was standing at the lateral side of the aerosol box. Both had PPE on and hands in the box's ports. A <b>balloon cuff</b> with 10 mL of <b>fluorescent fluid</b> was inserted in the manikin's pharynx and <b>inflated</b> with oxygen until it <b>burst</b> .	Only <b>the contents of the box</b> were <b>contaminated</b> , including the <b>hands and forearms</b> that were inside the box.	<b>The operator's and assistant's gloves, clothing, face mask and neck</b> were <b>contaminated</b> . <b>Within a radius of two metres</b> , the following surfaces were contaminated: <b>floor, bed, wall and computer</b> .
Braneki et al. (8)	Modified aerosol box with open feet-facing side	The operator's hands were inside the box's ports. In <b>the first part</b> of the experiment, a cough was simulated with a syringe, filled with 5 mL of <b>normal saline with fluorescent plastic particles</b> , connected to a <b>catheter</b> that led to <b>the hypopharynx</b> . <b>The second part</b> of the experiment was performed in a similar way, except that 10 mL of <b>ordinary fluorescent solution and a nebulizer</b> were used, generating smaller droplets and aerosols.	<b>Contamination</b> was limited to the <b>inside</b> of the aerosol box - <b>the operator's hands and PPE inside</b> the box. Due to the opening on the lower side of the box, the <b>manikin's chest and the lower limbs</b> were contaminated at a distance of <b>1.2 metres</b> from the aerosol box.	<b>PPE</b> and unprotected areas - <b>the operator's ear and neck</b> - were contaminated. <b>Surfaces and instruments</b> were contaminated within a <b>radius of 1.8 metres</b> . When using the nebulizer, the dispersion of the droplets was lower.

not escape from the box (31). By analyzing the removal of aerosols from a box covered with a plastic drape and an air extraction system, the researchers found that the half-life of the particles in the box is reduced. The latter was reduced from 3.4 minutes without the use of an air extraction system, and to less than 17 seconds when using it. In this way, the authors showed a significant reduction in the possibility of contamination using an active air extraction system (36). Simpson et al. also studied aerosol contamination by simulating five scenarios involving coughing. Particles with a diameter of 0.3 to 5 µm were measured with a meter placed in front of the operator's head. They compared the use of the original aerosol box design with the surface which faced the patient's feet covered with a plastic drape, and an updated aerosol box with an active air extraction

system and a particulate filter. Compared to the absence of all protective equipment, greater contamination was found when using the original aerosol box, as aerosols reached the operator through the large hand ports. The use of an aerosol box with an active air extraction system, filters and ports that were completely sealed with neoprene showed that the number of particles in the air near the operator's head was consistently similar to pre-contamination values. However, they have shown that the use of an unsuitable aerosol box can increase exposure to aerosol particles in the air (2). Therefore, the term "aerosol" box is incorrect, as the original box does not protect the operator and other healthcare staff from aerosol particles without updates, while an updated box with an active air extraction system can be a suitable part of PPE (2,52).

## 6 Drape as a replacement for an aerosol box

The aerosol box is receiving more attention in countries with less developed healthcare systems, while the reception is more varied in developed countries. Some authors report complications in procedures that need to be performed quickly and therefore advise against use (31). Their impracticality is also described in the USA, where it has been replaced by plastic drapes or sheets in some locations. Enami et al. have developed a drape to prevent disease transmission during endotracheal intubation. It consists of a clear plastic sheet with hand insertion ports placed closely around the patient (33,53). Preparation time takes five minutes, which is comparable to an aerosol box, and the cost of production is much lower at about \$2 (54). The drape should be disposed after each use. One of the major advantages of the drape is that it allows for manual dexterity as it can be moved. It also protects other healthcare staff in the room as it does not have open sides (26,33,53). Drapes can be placed in different ways. The use of non-sealing horizontal and vertical drapes protects the operator from macroscopic drops but not from aerosols (2). Rose et al. compared the operator and assistant macroscopic contamination using the original design of the aerosol box and plastic drape. They found that operator contamination was greatest with the drape and least with the aerosol box (55).

## 7 Conclusion

From the results of research to date, we can conclude that a properly updated aerosol box reduces the healthcare worker's exposure to water droplets and aerosols. On the other hand, an improperly designed aerosol box can only divert aerosols and cause even greater exposure of healthcare workers, while giving them a sense of false security. An aerosol box is also not suitable for use in situations where swift action is required. It is more useful in procedures where the extension of time is less important, e. g. endotracheal extubation. The importance of operator training should be stressed, including additional training with an aerosol box, as it is an additional physical barrier, which, due to limitations and changes in visibility, may affect the way interventions and procedures, which the operator is already experienced with, are performed. It is the author's opinion that no form of the aerosol box can reliably replace PPE. Its usefulness is seen mainly in reducing room and equipment contamination, e.g. endoscopy tower or microscope, which would allow better treatment of patients infected with SARS-CoV-2. Before it can be used in regular clinical practice, further improvements are required to ensure that the aerosol box is less restrictive for operators and easier and safer to use.

### Conflict of interest

None declared.

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