an improved alternative to static barrier enclosures to enhance the safety of healthcare providers performing aerosol-generating procedures without compromising patient care. Nonetheless, personal protective equipment (PPE) should remain the main defence during the coronavirus disease 2019 (COVID-19) pandemic.[3] With the threat of a potential second wave of infection as the world reopens,[10] any additional protective measures should not be overlooked. However, such measures should not trade off patient safety or create further exposure risks to healthcare providers after use.

Declarations of interest

The authors declare that they have no conflicts of interest.

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Systematic review of simulated airway management whilst wearing personal protective equipment

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Keywords: laryngeal mask airway; manikin; pandemic; personal protective equipment; tracheal intubation; videolaryngoscope

Editor—At the time of writing, there have been almost 7 million diagnosed cases of coronavirus disease 2019 (COVID-19) in 188 countries/regions with more than 400 000 deaths.[1] Approximately 2.3% of COVID-19 patients require tracheal intubation.[2] Because COVID-19 is a highly contagious disease, tracheal intubation is considered a high-risk procedure. A greater risk of contagion for healthcare workers performing tracheal intubation was described during the 2003 severe acute respiratory syndrome (SARS) epidemic[3,4] and was confirmed by a systematic review.[5]

Several recommendations[6–8] have been published providing suggestions to reduce the risk of viral transmission with airway management during COVID-19. Most recommendations agree on: planning ahead; wearing full personal protective equipment (PPE); involvement of senior staff; exposing the fewest possible healthcare workers; adequate

Table 1 Characteristics of included studies in the systematic review on simulation of airway management with participants wearing personal protective equipment (PPE). *National Health Service standardised CBRN-PPE (Respirex Internal Systems, Surrey, UK; and 3M United Kingdom plc, Bracknell, UK), which is a fully encapsulated suit incorporating a panoramic visor to improve vision but which retains the thick 'rubber' gloves that adversely affect fine motor skills. †DuPont (Wilmington, DE, USA) protective clothing (Tychem CPF3 and Tyvek suits), butyl rubber gloves, boots, and PA301S Powered Air Purifying Respirators (Bullard, Cynthiana, KY, USA). ‡Two pairs of gloves (Biogel® Indicator® Underglove; Mölnlycke Health Care, Schlieren, Switzerland; Sempermed® supreme surgical gloves sterile; Semperit AG, Vienna, Austria), chemical protective clothing (Tychem C™ with socks; DuPont), a hard hat (Versaflo™S-605-10; 3M Corp., St. Paul, MN, USA), and a respirator and 23 a Powered Air Purifying Respirator (PAPR) (Jupiter™ Powered Air Turbo Unit; 3M™; MN, USA). ¶Nylon shirt and pants (DuPont Tychem BR), antigas mask with active filter (3M Full-Facepiece 6800 DIN Respirator, Medium; 3M Corp.), gloves (North By Honeywell B324/9) and rubber boots HAZMAX Regular Steel Toe Boots). ||Tychem F CPF 2 (DuPont, Wilmington, DE, USA) encapsulating suit, Breathe Easy Butyl Hood System (3M Corp.; Maplewood, MN, USA) hooded powered air-purifying respirator (PAPR), nitrile gloves (Thermo Fisher Scientific, Waltham, MA, USA), and Ongard Boots (Thermo Fisher Scientific) as PPE. # Powered Air-Purifying Respirator, 3M Scott Safety Ltd, West Pimbo, Skelmersdale, UK. ** FRR, 3M Scott Safety Ltd, West Pimbo, Skelmersdale, UK. Airtraq IL: Indirect Laryngoscopy with standard Airtraq TM (size green, using the eyepiece); CI, confidence interval; DL: Direct Laryngoscopy. I-LMA: Intubating-Laryngeal Mask Airway; IQR, inter-quartile range; LMA: laryngeal mask airway; SD, standard deviation; VL: Video-laryngoscopy. In response to the letter by Sorbello and colleagues[19] accepted during the Advance Access prepublication stage, the table was updated with one additional study[20]. This did not affect the overall findings, but the table was updated in proof stage for completeness.

Authors, journal, year	Design of study	Manikin, airway	Population, PPE	Devices	Outcomes of airways management wearing PPE			
					Successful attempts (success rate)			Time (s) to
					<60 s		<120 s (overall)	Placement success, mean (SD)
Castle and colleagues, *Anaesthesia*, 2011	Randomised, crossover	Laerdal Advanced Airway Trainer, Unspecified airway setting	58 paramedics students, CBRN-PPE[1*]	LMA	47/58 (81%)		58/58 (100%)	48 (18)
				ProSeal	52/58 (90%)		57/58 (98%)	44 (16)
				i-gel	58/58 (100%)		58/58 (100%)	19 (8)
				Laringeal tube	55/58 (95%)		58/58 (100%)	38 (13)
				Combitube	25/58 (43%)		55/58 (95%)	65 (23)
				LMA-Fastrach	43/58 (74%)		58/58 (100%)	51 (18)
					Time unspecified			Intubation success, mean (95% CI)
Yousif and colleagues, *Prehosp. Disaster Med.*, 2017	Prospective, randomised, crossover	Laerdal Resusci-Anne manikin system, Normal airway setting	20 prehospital providers Level C PPE[†]	DL	19/20 (95%)			28 (22–29)
				Glidescope VL	20/20 (100%)			36 (3240)
				KingVision VL	20/20 (100%)			30 (26–43)
					<240 s (overall)			Ventilation success, mean (IQR)
Plazikowski and colleagues, *Infect. Control Hosp. Epidemiol.*, 2018	Randomised, controlled	Laerdal Airway Management Trainers, Unspecified airway setting	30 anaesthesiologists Level C PPE[‡]	i-gel	30/30 (100%)			10 (8–11)
				LMA-Fastrach	30/30 (100%)			10 (8–12)
				DL	30/30 (100%)			24 (20–29)
				Airtraq VL	27/30 (90%)			29 (23–48)
				Ambu fiberoptic-aScope	29/30 (97%)			51 (40–88)
				Melker cricothyrotomy set	30/30 (100%)			58 (45–69)
					<60 s	<120 s	<150 s (overall)	Intubation success, mean (SD)
Castle and colleagues, *Resuscitation*, 2011	Randomised, crossover	Laerdal Advanced Airway trainer™, Unspecified airway setting	66 paramedic students, CBRN-PPE[*]	DL	50/66 (76%)	60/66 (91%)	61/66 (92%)	50 (21)
				DL with stylet	48/66 (73%)	61/66 (92%)	61/66 (92%)	51 (17)
				DL with Bougie	38/66 (58%)	60/66 (91%)	61/66 (92%)	58 (20)
				DL with McCoy	46/66 (70%)	53/66 (80%)	54/66 (82%)	51 (16)
				Airtraq VL	33/66 (50%)	53/66 (80%)	56/66 (85%)	70 (38)
				I-LMA	39/66 (59%)	63/66 (95%)	64/66 (97%)	61 (20)
					<60 s (overall)			Intubation success (mean)
				DL	25/32 (78%)			29

Continued

Table 1 Continued

Authors, journal, year	Design of study	Manikin, airway	Population, PPE	Devices	Outcomes of airways management wearing PPE		
					Successful attempts (success rate)	Time (s) to	
Wedmore and colleagues, *Mil. Med.*, 2003	Prospective, observational	Laerdal intubating head manikin, Unspecified airway setting	16 EM residents with prior airway experience, NBC PPE (N-40 mask)	I-LMA	32/32 (100%)	25	
					<120 s (overall)	Intubation success, mean (IQR)	
Shin and colleagues, *Emerg. Med. J.*, 2013	Randomised, crossover	Laerdal Airway Management Trainer, Unspecified airway setting	31 medical doctors (19 with prior intubation experience) CBRN-PPE[¶]	DL with stylet Pentax-AWS VL	30/31 (97%) 31/31 (100%)	26 (23–35) 18 (15–22)	
					Time unspecified	Ventilation success, mean (SD)	
Aberle and colleagues, *Prehosp. Disaster Med.*, 2015	Randomised, crossover	SimMan 3G, Unspecified airway setting	21 EM residents, HazMat PPE[§]	DL GlideScope Cobalt VL	20/21 (95%) 21/21 (100%)	10 (5) 8 (3)	
					Time unspecified	To intubation success, mean (±SD)	
						Powered respirator	Standard respirator
Schumacher and colleagues, Anaesthesia., 2020	Randomised, crossover	Laerdal Airway Management TrainerTM, Difficult airway setting	25 anesthesiologists, 3M Scott-Duraflow Platform[#] and First Responder Respirator[**]	DL Airtraq IL Airtraq VL Ambu A/S	25/25 (100%) 25/25 (100%) 25/25 (100%) 25/25 (100%)	16 (6) 169 11 (3) 39 (4)	15.1 (5) 19.2 (5) 10.0 (2) 40.1 (5)

pre-oxygenation; avoiding manual bag-mask ventilation; rapid-sequence induction whenever possible; use of videolaryngoscopy, ideally with a distant screen display that allows distancing of operators from the patient's airway; and availability of a second-generation supraglottic airway device. These recommendations are mostly based on experience acquired during present[7] and previous[9] pandemics, with no supporting evidence from controlled studies. In order to evaluate the current evidence on best practices for tracheal intubation whilst wearing PPE, we conducted a systematic review of the literature looking at manikin-based simulation studies investigating airway management under the constraints of wearing PPE.

We systematically searched the MedLine database with the last update on June 1, 2020; the MESH terms 'airway', 'simulat*', and 'manikin' were combined. We included studies investigating tracheal intubation or supraglottic airway device insertion in simulated adult scenarios. The outcomes of interests were the success rate and time-to-intubation (or correct placement). We applied the following restrictions: only articles providing an abstract and published in the English language were included. Two pairs of assessors screened the titles and abstracts for suitability (FS, ST, GJP, and PM), with a fifth assessor (MA) arbitrating any disagreements.

Our systematic search produced 3101 titles. After screening the abstracts against inclusion criteria, we selected 12 articles for full-text evaluation. Further screening excluded five titles: one was performed in a paediatric setting, three compared time to ventilation with tracheal intubation *vs* laryngeal mask airway (two studies) or King Laryngeal Tube (one study), and one study evaluated intubation in different positions only with direct laryngoscopy. No further findings were retrieved by the manual search.

Seven studies were included in the initial analysis.[10–16] Table 1 shows study characteristics and most relevant findings. Five studies investigated only intubation,[11,12,14–16] one evaluated only supraglottic airway device placement,[10] and one included both intubation, supraglottic airway device placement and cricothyroidotomy.[13] The participants in these studies ranged from paramedic students (with no airway management experience[1011]) to anaesthesiologists[13]; the number of participants ranged from 1616 to 66.[11] The type of PPE worn also varied considerably.

Six studies evaluated tracheal intubation with direct laryngoscopy (in some cases with stylet or bougie[11]), with time to intubation ranging from 24 to 29 s, apart from one study whose participants were paramedic students reporting longer times (>50 s[11]). The success rate with direct laryngoscopy ranged from 78% to 100%.

Four different videolaryngoscopy devices were evaluated in five studies: Airtraq®,[11,13] Pentax-AWS®,[15] KingVision®,[12,14] and Glidescope®.[12,14] Time to intubation varied substantially between devices: Airtraq® 29–69 s, Pentax-AWS® 18 s, KingVision® 30 s, and Glidescope® 8–36 s. The success rate was 80–90% for Airtraq®, and 100% for Pentax-AWS®, KingVision® and Glidescope®.

In two studies the videolaryngoscopes Pentax-AWS® and Glidescope® performed better than direct laryngoscopy both for time to intubation and success rate.[14,15] In one study both KingVision® and Glidescope® had a better success rate than direct laryngoscopy but longer time to intubation.[12] In the remaining two studies, Airtraq® had poorer performances than direct laryngoscopy both in terms of success rate and time to success[11,13]

Two studies evaluated the intubating laryngeal mask airway[11,16] with divergent findings in time to intubation (one study included paramedic students[11] and one involved emergency medicine residents with prior airway experience[16]). The only study evaluating the positioning of six supraglottic airway devices for ventilation found that i-gel® had the best performances, with 100% success rate within 60 s and the shortest time to placement (19 s). Furthermore, i-gel® was the only device where successful placement was in some cases reported within 15 s.[10]

Our systematic review highlights a significant knowledge gap regarding airway management under simulated conditions of wearing PPE. We found high heterogeneity in study design, devices investigated, procedure performed, and outcomes analysed; therefore, it is difficult to draw solid conclusions.

We believe there is urgent need for comparative studies investigating strategies for airway management in situations with high-risk of contagion such as during a respiratory infection pandemic. Interestingly, we found only one study performed with anaesthesiologists as subjects.[13] Two studies have confirmed that even staff with prior experience took significantly longer to achieve successful airway management whilst wearing PPE compared with not wearing it.[17,18] Clinical studies with risk of contamination with highly infectious pathogens would be unethical, so simulation studies should be encouraged for two main reasons. Firstly, healthcare workers participating in simulation whilst wearing PPE may gain more confidence in managing these difficult scenarios. Moreover, we suggest that simulation of airway management whilst wearing PPE should become part of the training curriculums in the future. Secondly, comparative studies may evaluate different aspects, comparing the techniques/approaches with the highest success rate and those with fastest achievement of goals. As an example, in one study videolaryngoscopy had a better success rate but took longer times to complete the procedure.

Comparative studies may produce different results than those expected by theoretical models. For example, one study[15] found that Glidescope® (un-channelled, distant monitor) had a 6 s slower time to intubation than KingVision® (channelled, monitor on scope). In theory, one would expect a more comfortable and easier visualisation of vocal cords with the use of a videolaryngoscope with a distant screen whilst wearing PPE.

Our systematic review found few studies on airway management by operators wearing PPE. The large heterogeneity of these studies does not warrant a quantitative analysis, but it suggests an urgent need to design large simulation studies with personnel potentially exposed to aerosol-generating procedures such as airway management.

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Declarations of interest

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Tracheal introducers and airway trauma COVID-19. Comment on *Br J Anaesth* 2020; 125: e168–e170

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