

ANESTHESIOLOGY

Emergency Airway Management in Patients with COVID-19: A Prospective International Multicenter Cohort Study

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- IntubateCOVID is a large, multinational, multispecialty, voluntary, self-reported database of healthcare workers who have performed intubations on patients with known or suspected COVID-19 established shortly after the widespread onset of the pandemic in March 2020. Data collection focuses on practitioner and hospital level characteristics related to the intubation, and no patient identifiable characteristics are collected. Practitioners record any subsequent symptoms suggestive of COVID-19 or positive tests for it.

What This Article Tells Us That Is New

- The authors report a secondary analysis of associations of intubation and operator characteristics related to the primary outcome of first-attempt intubation success in 4,476 intubations among 1,722 clinicians at 607 institutions across 32 countries, also considering differential rates of success between high-income and low- and middle-income countries.
- Although successful first-attempt intubation was noted in 89.7% of intubations, 0.5% required four or more attempts, an emergency surgical airway was required in 0.2%, and a composite variable of failed intubation occurred in 0.8%.

ABSTRACT

Background: Tracheal intubation for patients with COVID-19 is required for invasive mechanical ventilation. The authors sought to describe practice for emergency intubation, estimate success rates and complications, and determine variation in practice and outcomes between high-income and low- and middle-income countries. The authors hypothesized that successful emergency airway management in patients with COVID-19 is associated with geographical and procedural factors.

Methods: The authors performed a prospective observational cohort study between March 23, 2020, and October 24, 2020, which included 4,476 episodes of emergency tracheal intubation performed by 1,722 clinicians from 607 institutions across 32 countries in patients with suspected or confirmed COVID-19 requiring mechanical ventilation. The authors investigated associations between intubation and operator characteristics, and the primary outcome of first-attempt success.

Results: Successful first-attempt tracheal intubation was achieved in 4,017/4,476 (89.7%) episodes, while 23 of 4,476 (0.5%) episodes required four or more attempts. Ten emergency surgical airways were reported—an approximate incidence of 1 in 450 (10 of 4,476). Failed intubation (defined as emergency surgical airway, four or more attempts, or a supraglottic airway as the final device) occurred in approximately 1 of 120 episodes (36 of 4,476). Successful first attempt was more likely during rapid sequence induction *versus* non-rapid sequence induction (adjusted odds ratio, 1.89 [95% CI, 1.49 to 2.39]; $P < 0.001$), when operators used powered air-purifying respirators *versus* nonpowered respirators (adjusted odds ratio, 1.60 [95% CI, 1.16 to 2.20]; $P = 0.006$), and when performed by operators with more COVID-19 intubations recorded (adjusted odds ratio, 1.03 for each additional previous intubation [95% CI, 1.01 to 1.06]; $P = 0.015$). Intubations performed in low- or middle-income countries were less likely to be successful at first attempt than in high-income countries (adjusted odds ratio, 0.57 [95% CI, 0.41 to 0.79]; $P = 0.001$).

Conclusions: The authors report rates of failed tracheal intubation and emergency surgical airway in patients with COVID-19 requiring emergency airway management, and identified factors associated with increased success. Risks of tracheal intubation failure and success should be considered when managing COVID-19.

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EDITOR'S PERSPECTIVE (Continued)

- Multivariable analysis demonstrated that successful first attempts were more likely with rapid sequence intubations, when operators used powered air-purifying respirators, and with increasing operator experience.
- Intubations performed in low- and middle-income countries were nearly half as likely to be successful on first attempt than in high-income countries.
- These results provide potentially useful information for global and local policy-making related to this and future pandemics. However, the observational nature, along with lack of patient level characteristics, leave room for residual confounding of these associations.

Airway management is generally safe and well understood, and the risks of tracheal intubation in different settings are reasonably clear.^{1,2} However, since the World Health Organization (Geneva, Switzerland) declared COVID-19 a pandemic on March 11, 2020,³ novel factors never before considered are now complicating clinical practice and changing the way airways are managed on an international scale.

Tracheal intubation in patients with suspected or confirmed COVID-19 may introduce significant risk to patients and healthcare workers. In addition, patient secretions containing SARS-CoV-2 may be aerosolized during airway management. Airway managers and their teams must don appropriate personal protective equipment to minimize risk to themselves and others.^{4,5} For these reasons, safe airway management during the pandemic has been a subject of intense interest and speculation in the literature.⁶⁻⁹

As with many other practices during the pandemic, airway management strategies may have changed rapidly during this period despite the paucity of strong evidence. Recommendations were published early on in the pandemic by expert clinicians to guide professionals on tracheal intubation practices to maximize patient and healthcare worker safety.¹⁰⁻¹² Common themes of these recommendations included limiting the number of personnel involved in the procedure, wearing appropriate personal protective equipment, deploying the most skilled airway manager to perform airway management interventions, using videolaryngoscopy as the primary intubation device, and

avoiding the use of potential aerosol-generating procedures such as high-flow nasal oxygenation and bag-valve-mask ventilation.¹³

While the evidence-base for procedural staff safety continues to build, the conduct and patient-centered risks of airway management procedures in patients with COVID-19 have not been widely reported. Moreover, regional and global variation in airway management and associated outcomes may also exist, particularly between high-income countries with more well-developed healthcare systems and low- and middle-income countries with fewer resources, but there are no comparative data available. At the same time, many of the published recommendations have been written from the perspectives of clinicians practicing in high-income countries, with little consideration made for potential differences in access to airway tools, resources, training, and/or staffing that might exist in less resource-rich environments.

We therefore sought to describe the international practice of airway management during the pandemic using data from the intubateCOVID registry, a multinational collaboration of healthcare professionals involved in airway management of patients with suspected and confirmed COVID-19 that was rapidly convened after the pandemic declaration.¹⁴ Our objectives for this study were to (1) estimate the rate of success and complications during tracheal intubation attempts; (2) describe the international practices of airway management in patients with suspected or confirmed COVID-19; and (3) determine whether global variations in practices and outcomes exist between high-income countries and low- and middle-income countries. We hypothesized that the success of emergency airway management in patients with COVID-19 is associated with geographical and procedural factors.

Materials and Methods

We performed a prospective, international, multicenter, observational cohort study and report our findings according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.¹⁵ We extracted data from intubateCOVID, an international registry of user-reported cases of airway management in patients with suspected or confirmed COVID-19, and undertook a secondary analysis of these data previously collected for the purpose of surveilling the risk of COVID-19 transmission among healthcare workers involved in COVID-19 airway management. Cases of airway management performed between March 23, 2020, and October 24, 2020, were included. Healthcare workers involved in airway management procedures for patients with suspected or confirmed COVID-19 were informed about the registry *via* national and international professional organizations and social media, and were invited to voluntarily self-report their airway management episodes in patients with suspected or confirmed COVID-19.

This article is accompanied by an editorial on p. 212. Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are available in both the HTML and PDF versions of this article. Links to the digital files are provided in the HTML text of this article on the Journal's Web site (www.anesthesiology.org). This article has a visual abstract available in the online version. D.J.N.W. and K.E.-B. contributed equally to this article.

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Dataset Details and Variables

Registry data were collected *via* a secure Web-based database (Knack.com; Evenly Odd, Inc., USA). At registration, users recorded their baseline characteristics, including institution and country of practice, and thereafter used the registry to record details of any tracheal intubation procedures they were involved in. Users were permitted to submit data about any airway management episode they had clinical involvement in, either as an operator (person performing the airway procedure) or as an assistant (present at the bedside during the procedure, but not directly performing the airway procedure). Data on the use of personal protective equipment, procedural performance of the airway management procedure, and outcomes of airway management were collected, including specific procedure-related details such as whether rapid sequence induction was performed, laryngoscopy devices used, the use of apneic oxygenation, bag-mask ventilation, and supraglottic airway devices. All data points were mandatory fields to minimize the risk of missing data. A calculated variable acting as a surrogate for cumulative clinical experience with performing COVID-19 tracheal intubations was derived, which was defined as the number of previous recorded intubation episodes in the registry by the same operator before the current episode (*e.g.*, for an operator who recorded three intubations in the registry, the first will record zero, the second will record one, and the third will record two previous intubations). Further details of the intubateCOVID registry data collection process, including full inclusion and exclusion criteria, have previously been described.¹⁴ Only cases reported by operators performing the airway management procedure were included to ensure duplicate episodes were not analyzed. We included only airway management attempts for patients with suspected or confirmed COVID-19 requiring tracheal intubation for the following indications related to primary respiratory deterioration due to COVID-19: deteriorating respiratory failure requiring mechanical ventilation, airway protection for low Glasgow Coma Score, and cardiorespiratory arrest. We excluded cases of airway management for the following indications: elective tracheostomy insertion, general anesthetic for surgery, other airway manipulation in the intensive care unit (ICU) such as tracheal tube exchange, and other indications.

Definitions for country income level categories are taken from the Organisation for Economic Co-operation and Development (Paris, France), Development Assistance Committee List of Official Development Assistance Recipients, which lists all countries and territories eligible to receive official development assistance, and is based on gross national income per capita (available at: <http://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/>; accessed April 13, 2021). Low- and middle-income countries were defined by this list as countries with a gross national income per capita of less than or equal to USD\$12,235 in 2016. A full list

of countries where data were collected and their income category are available in Supplemental Digital Content 1 (<http://links.lww.com/ALN/C617>).

For the purposes of this analysis, our primary outcome was successful tracheal intubation at first attempt. The secondary outcomes were incidence of emergency surgical airways (needle cricothyroidotomy, cannula cricothyroidotomy, or tracheostomy) and incidence of failed tracheal intubations. Failed tracheal intubations were defined according to Difficult Airway Society (London, United Kingdom) guidelines as four or more attempts at intubation, the final recorded airway device being a supraglottic airway device, or the need for emergency surgical airway.¹⁶

Study Governance

Institutional review at the lead site in the United Kingdom, Guy's and St Thomas' National Health Service Foundation Trust (London, United Kingdom), determined that data collection for the registry did not require ethics approval based on United Kingdom Health Research Authority (London, United Kingdom) guidance for service evaluations (service evaluation identification No. 10769). Similar determinations were subsequently obtained by at least one site in all other participating countries. (Further details of governance approvals in other jurisdictions are available at: <https://intubatecovid.org/supporting-documents>; accessed April 13, 2021.) Data were stored and processed in compliance with European Union General Data Protection Regulations and the European Union–United States Privacy Shield Framework (Washington, D.C.). Individual user registration and subsequent data submission were completely voluntary, and at the point of registering their details in the online registry, all participants gave consent to be contacted for ongoing follow-up with the study, for inclusion of their data in this study for presentation or publication, and for their data to be stored in an online encrypted database with access to the data granted only to the study team in accordance with General Data Protection Regulations principles.

Statistical Analysis

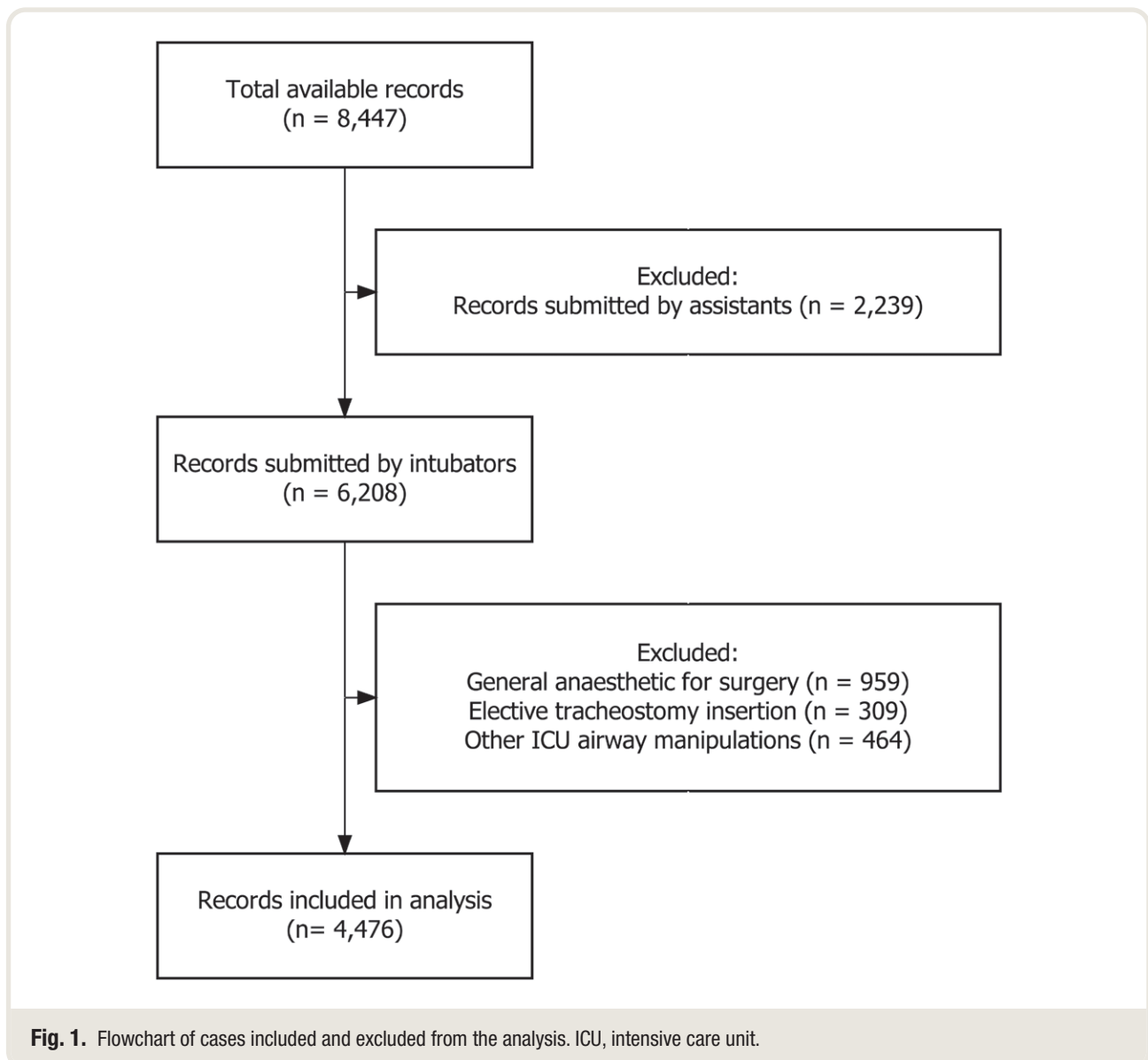
Descriptive statistics of the characteristics of tracheal intubation episodes and outcomes of tracheal intubation attempts are reported in aggregate and stratified by country income level. Continuous variables are reported as mean \pm SD for normally or uniformly distributed data, or median (interquartile range) for data with skewed distributions. For discrete variables, numbers and proportions are reported.

Differences in proportions between low- and middle-income countries and high-income countries for the presence of certain intubating characteristics were compared using a two-sample chi-square test independence with the Yates's continuity correction. To account for clustering of tracheal intubation episodes within operator,

mixed-effects logistic regression models with random intercepts were used in univariable and multivariable analyses. First, univariable analyses were performed to investigate associations between variables describing intubating characteristics and operator characteristics, and the pre-specified binary outcome of successful tracheal intubation at first attempt. Then a multivariable model was fitted including all covariates significant in univariable analysis to investigate which variables were independently associated with the outcome while adjusting for confounders. Variables included in the regression modeling were chosen based on clinical and scientific plausibility for influencing the successful performance of intubation. To facilitate mixed-effects model fit, age was standardized using grand mean centering and rescaling to SD units. None of the variables were analyzed as effect modifiers.

Proposed relationships between the variables and the outcome are illustrated in a directed acyclic graph (Supplemental Digital Content 1, supplemental fig. 1, <http://links.lww.com/ALN/C617>). A further sensitivity analysis was performed *post hoc* to investigate whether our findings could be substantially affected by informative cluster size as cluster size was associated with the outcome (an increased number of intubations is associated with greater first-attempt success). For this sensitivity analysis, we analyzed only the first recorded intubation episode for each operator, thereby eliminating the effect of clustering. We repeated the multivariable analysis using a fixed effects-only logistic regression model with the same covariates minus the number of previous COVID-19 intubations.

For all statistical tests, a two-sided *P* value of less than 0.05 was considered statistically significant. No sample size



analysis was performed, and a sample maximizing the use of all eligible registry data from the time period was used for this study. The data analysis and statistical plan were written after the data were accessed. All analyses were performed in R version 3.5.2 (R Foundation for Statistical Computing, Vienna, Austria). All deidentified individual participant data that underlie the results reported in this article are available on request, along with the statistical analysis code.

Results

After exclusions, a total of 4,476 tracheal intubation episodes was included in the analysis (fig. 1). These were recorded from 607 institutions across 32 countries (fig. 2 and Supplemental Digital Content 1, supplemental table 1, <http://links.lww.com/ALN/C617>) and were submitted by 1,772 operators. There were no missing data. The majority of tracheal intubations were performed in patients with confirmed COVID-19 at the time of the airway management episode ($n = 3,017$; 67.4%). Operators reported a median (interquartile range) of 1 (1 to 3) tracheal intubation episodes. Other operator characteristics are reported in table 1.

Worldwide, rapid sequence induction was used in 3,457 (77.2%) tracheal intubations, and bag-mask ventilation was used in 889 (19.9%) tracheal intubations. Videolaryngoscopes

were the first-attempt laryngoscopy device in 3,366 (75.2%) episodes worldwide. The use of videolaryngoscopy during the first attempt at tracheal intubation was more frequent in high-income countries than in low- and middle-income countries (81.9% and 43.9%, respectively; $P < 0.001$). Apneic oxygenation was more frequently reported for tracheal intubation attempts in low- and middle-income countries (82.0%) compared to attempts in high-income countries (51.8%; $P < 0.001$). Other characteristics of recorded tracheal intubation episodes are summarized in table 2.

Personal Protective Equipment

Personal protective equipment use was generally good (fig. 3), with the majority ($n = 3,930$; 87.8%) of operators using World Health Organization–recommended minimum standards for personal protective equipment (eye protection, respirator mask, gown, and gloves) during tracheal intubation. The proportion of operators using World Health Organization–recommended minimum standards for personal protective equipment was higher in low- and middle-income countries than in high-income countries (93.2% and 86.6%, respectively; $P < 0.001$). The use of plastic drapes/boxes was also significantly higher in low- and middle-income countries (36.4%) compared to high-income countries (5.1%; $P < 0.001$).

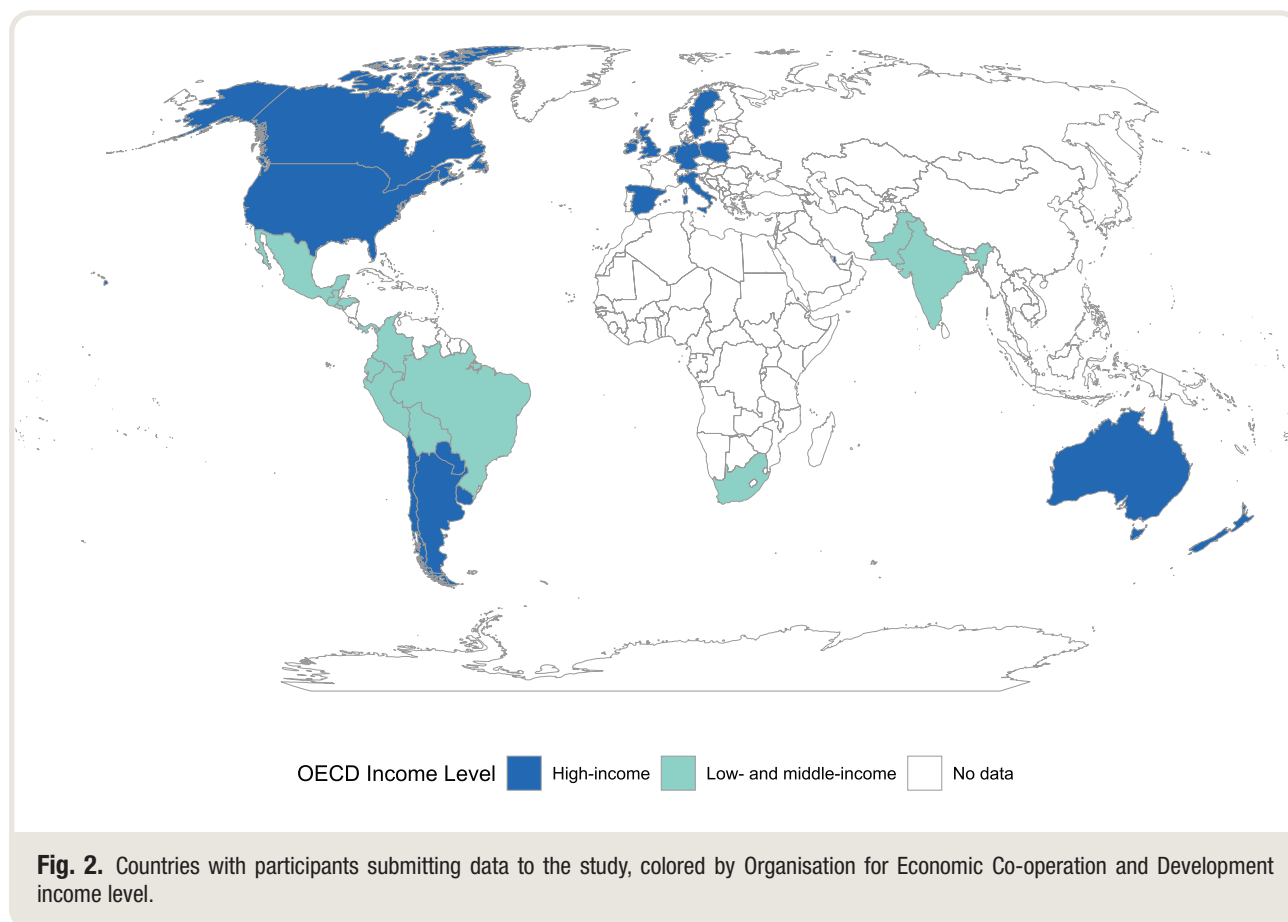


Fig. 2. Countries with participants submitting data to the study, colored by Organisation for Economic Co-operation and Development income level.

Table 1. Participant Characteristics

	Overall (n = 1,772)
Age, yr, median [interquartile range]	40 [34, 46]
Sex	
Male, No. (%)	1,119 (63.1)
Specialty, No. (%)	
Anesthesiology	1,444 (81.5)
Intensive care medicine	272 (15.3)
Other	56 (3.2)
Role, No. (%)	
Physician (consultant/attending grade)	1,285 (72.5)
Physician (training grade)	372 (21.0)
Nonphysician	115 (6.5)
Country, No. (%)	
Australia	125 (7.1)
Canada	49 (2.8)
Chile	10 (0.6)
Germany	33 (1.9)
Hong Kong Special Administrative Region	25 (1.4)
India	81 (4.6)
Ireland	23 (1.3)
Pakistan	19 (1.1)
Poland	32 (1.8)
Qatar	19 (1.1)
South Africa	52 (2.9)
Spain	11 (0.6)
Sweden	70 (4.0)
The Netherlands	28 (1.6)
United Kingdom	700 (39.5)
United States of America	449 (25.3)
Other	46 (2.6)
Country income status, No. (%)	
High-income	1,595 (90.0)
Low- and middle-income	177 (10.0)

Nonphysician roles include certified registered nurse anesthetists and other registered nursing professionals, operating department practitioners, physician associates, anesthesia associates, advanced critical care practitioners, and paramedics. Countries with fewer than 10 participants have been recategorized as "Other." These include Argentina, Bolivia, Brazil, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Italy, Mexico, New Zealand, Panama, Paraguay, Peru, Singapore, and Uruguay.

Outcomes and Complications

Successful tracheal intubation at first attempt was achieved in 4,017 cases (89.7%), while there were 23 cases (0.5%) requiring four or more attempts (table 3). A total of 10 emergency surgical airways were reported—an approximate rate of 1 in 450. The final airway device inserted was a supraglottic airway device in 6 cases (0.1%). The overall rate for failed tracheal intubation was 0.8% or approximately 1 in 120 (n = 36; see Supplemental Digital Content 1, supplemental table 2, <http://links.lww.com/ALN/C617>, for a summary of the characteristics of difficult and failed intubation cases).

In the multivariable mixed-effects model, operators with increasing numbers of previous recorded COVID-19 intubations were more likely to be successful at first attempt (adjusted odds ratio, 1.03 for each additional previous intubation performed [95% CI, 1.01 to 1.06]; $P = 0.015$; fig. 4). Operators were also more likely to be successful if they

were wearing powered air purifying respirators than if they were wearing nonpowered respirator masks (e.g., FFP2/FFP3/N95/N99) only (adjusted odds ratio, 1.60 [95% CI, 1.16 to 2.20]; $P = 0.006$). Rapid sequence induction was associated with an increased likelihood of successful first attempt (adjusted odds ratio, 1.89 [95% CI, 1.49 to 2.39]; $P < 0.001$). The use of videolaryngoscopy, nonpowered respirator masks, plastic drapes/intubation boxes, intubation location, and indication for intubation did not appear to be associated with success at first attempt. The rate of successful tracheal intubation at first attempt was greater in high-income countries (90.3%) than in low- and middle-income countries (87.1% [unadjusted odds ratio for successful first attempt in low- and middle-income countries, 0.59; 95% CI, 0.42 to 0.82; $P = 0.002$]). This effect persisted after adjustment for other covariates (adjusted odds ratio, 0.57 [95% CI, 0.41 to 0.79]; $P = 0.001$) in the full multivariable regression model (table 4). A *post hoc* sensitivity analysis for including only the first recorded intubation episodes for each operator did not show substantial differences in the associations identified in our main analysis (Supplemental Digital Content 1, supplemental table 3, <http://links.lww.com/ALN/C617>).

Discussion

We conducted a large prospective study of airway management in critically ill patients with COVID-19 and report novel data that increase the understanding of risks to patients requiring emergency tracheal intubation. Worldwide, the use of videolaryngoscopy and first-attempt success for tracheal intubation attempts in patients with COVID-19 during the pandemic were high. The incidence of difficult or failed tracheal intubation was approximately 1 in 120, while the rate of emergency surgical airway was approximately 1 in 450 tracheal intubation episodes. Successful first-attempt tracheal intubation was more likely during rapid sequence induction, when operators were wearing powered air-purifying respirators, and when performed by operators with more previous recorded COVID-19 tracheal intubations within the registry. Our data highlight possible differences between low- and middle-income countries and high-income countries in terms of tracheal intubation characteristics and success at first intubation attempt (adjusted odds ratio, 0.57 [95% CI, 0.41 to 0.79]).

Tracheal intubation in patients with COVID-19 is considered a high-risk procedure for both the patient and the healthcare workers involved in performing the procedure.¹⁰ Patients admitted to the hospital with COVID-19 respiratory failure requiring invasive mechanical ventilation have a high mortality.^{17–20} Although the literature thus far has focused on the morbidity and mortality risks of COVID-19 patients in the medium to long term after tracheal intubation after a period of prolonged ventilation, there are few reports about the immediate complications

Table 2. Tracheal Intubation Characteristics

	Overall (n = 4,476)	High-income (n = 3,683)	Low- and Middle- income (n = 793)	P Value
Location				< 0.001
Intensive care unit	2,818 (63.0)	2,179 (59.2)	639 (80.6)	
Emergency department	781 (17.4)	705 (19.1)	76 (9.6)	
Operating theater suite	118 (2.6)	112 (3.0)	6 (0.8)	
Other hospital location	759 (17.0)	687 (18.7)	72 (9.1)	
Indication				0.199
Deteriorating respiratory failure	3,999 (89.3)	3,300 (89.6)	699 (88.1)	
Airway protection for low Glasgow Coma Scale	287 (6.4)	225 (6.1)	62 (7.8)	
Cardiac arrest	190 (4.2)	158 (4.3)	32 (4.0)	
Total number of staff in intubation room				< 0.001
1	33 (0.7)	11 (0.3)	22 (2.8)	
2	286 (6.4)	213 (5.8)	73 (9.2)	
3	2,681 (59.9)	2,084 (56.6)	597 (75.3)	
4	925 (20.7)	853 (23.2)	72 (9.1)	
5+	551 (12.3)	522 (14.2)	29 (3.7)	
Operator role				< 0.001
Anesthetic doctor	3,648 (81.5)	3,096 (84.1)	552 (69.6)	
Intensive care doctor	595 (13.3)	378 (10.3)	217 (27.4)	
Anesthetic nurse/operating department practitioner	127 (2.8)	127 (3.4)	0 (0.0)	
Other doctor	67 (1.5)	45 (1.2)	22 (2.8)	
Others	39 (0.9)	37 (1.0)	2 (0.3)	
Airway assistant				< 0.001
Anesthetic nurse/operating department practitioner	1,816 (40.6)	1,676 (45.5)	140 (17.7)	
Anesthesiologist	584 (13.0)	482 (13.1)	102 (12.9)	
Intensive care doctor	473 (10.6)	241 (6.5)	232 (29.3)	
Other doctor	162 (3.6)	97 (2.6)	65 (8.2)	
Other nurse	934 (20.9)	719 (19.5)	215 (27.1)	
Others	507 (11.3)	468 (12.7)	39 (4.9)	
Rapid sequence induction	3,457 (77.2)	2828 (76.8)	629 (79.3)	0.134
First-attempt laryngoscopy device				< 0.001
Direct laryngoscope	1,100 (24.6)	655 (17.8)	445 (56.1)	
Videolaryngoscope	3,366 (75.2)	3,018 (81.9)	348 (43.9)	
Fiberoptic intubation	10 (0.2)	10 (0.3)	0 (0.0)	
Apneic oxygenation device used				< 0.001
Facemask oxygen*	1,790 (40.0)	1,370 (37.2)	420 (53.0)	
Conventional nasal cannula	273 (6.1)	169 (4.6)	104 (13.1)	
High flow nasal oxygenation	493 (11.0)	367 (10.0)	126 (15.9)	
None of the above	1,920 (42.9)	1,777 (48.2)	143 (18.0)	
Bag mask ventilation used	889 (19.9)	657 (17.8)	232 (29.3)	< 0.001
Personal protective equipment mask				0.129
Nonpowered respirator only	3,510 (78.4)	2,909 (79.0)	601 (75.8)	
Powered air-purifying respirator	905 (20.2)	724 (19.7)	181 (22.8)	
No mask or surgical mask only	61 (1.4)	50 (1.4)	11 (1.4)	

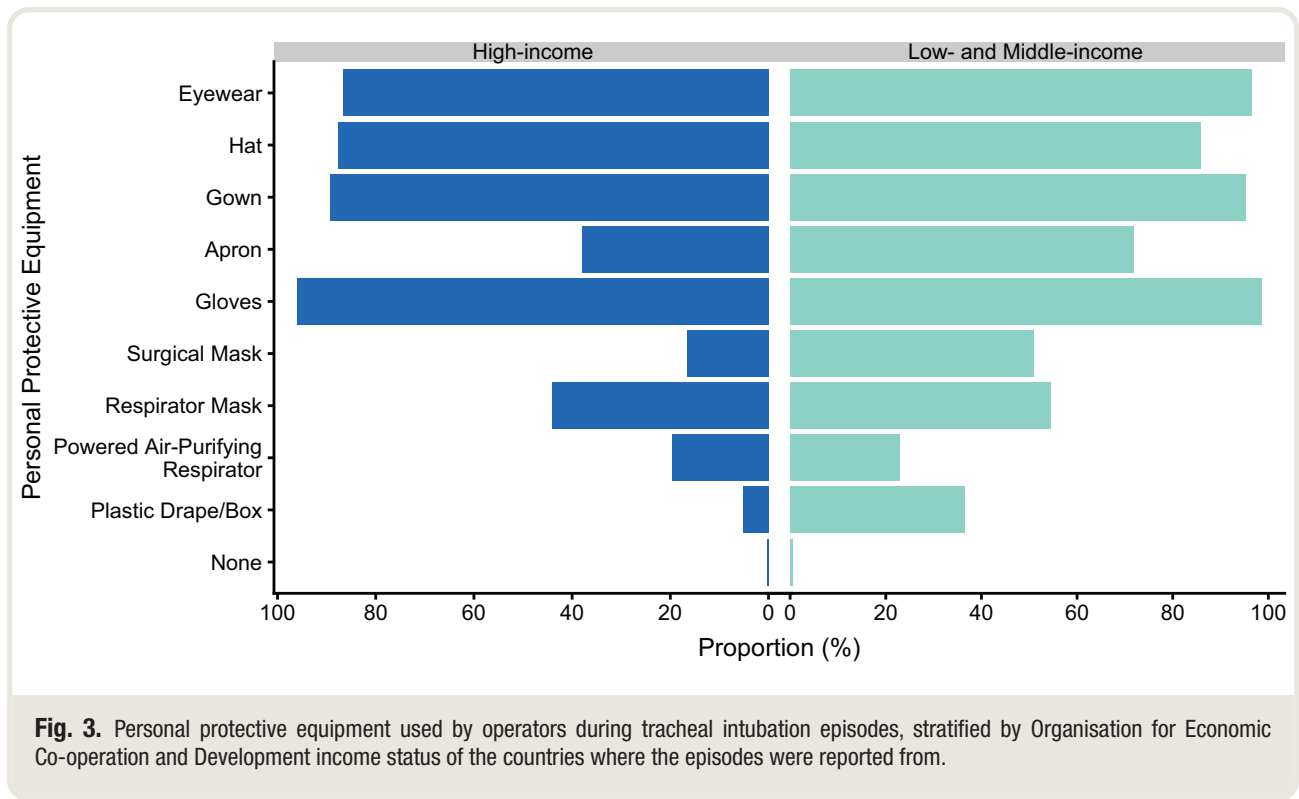
Data are number (percentage).

*Facemask oxygen is defined as the use of a facemask with oxygen delivered in an apneic patient without bag-mask ventilation.

seen during the period of tracheal intubation itself—at which point patients are at greatest risk of acute complications. However, this evidence gap has been extensively investigated before the pandemic, and the data reported herein juxtapose airway management in patients with and without COVID-19.

In a range of airway management settings outside the context of COVID-19, the reported incidence of failed tracheal intubation has previously been reported as approximately 1 in 700,²¹ and the rate of emergency surgical airway has been estimated at between 1 in 1,400^{21,22} and 1 in 50,000 in single-country data^{1,2,23}; however, the risk of failed intubation is recognizably higher in emergency

settings.^{2,24} Previous data reporting the rates of emergency surgical airway in critically ill patients range from 0 to approximately 1 in 500.^{25,26} Indeed, our reported rates are comparable with rates of failed intubation and emergency surgical airway in the hazardous environment of prehospital trauma, reported in an earlier study by Lockey *et al.* at 0.7% and 0.5%, respectively.²⁷ The reasons for the high risks reported in our cohort are likely to be multifactorial, involving a complex interplay of patients with a physiologically difficult airway and at risk of early decompensation requiring rapid progression to emergency surgical airway, variable access to COVID-19-specific airway management training, logistical challenges in patient management,



operator anxiety regarding viral transmission hampering performance, or the impact of personal protective equipment encumbering communication, comfort, and procedural proficiency. This last possibility may be supported by our finding that the use of powered air-purifying respirators conferred a higher likelihood of successful tracheal intubation at the first attempt, potentially due to increased comfort, visibility, or other residual confounders such as availability of other resources in high-income countries. Data regarding the impact of personal protective equipment on the risks to airway management patients are not available in the clinical setting, although these have been suggested in preclinical studies,²⁸ and further studies are necessary for non-COVID-19 practice. Notably, the definition of difficult intubation is highly variable; therefore, comparing this outcome in our study with other data is challenging.

We found that previous reported experience with intubation of COVID-19 patients, which was included as a term in our models as the number of previous recorded

COVID-19 intubations performed before the current intubation episode, was significantly associated with an increased likelihood of successful first attempt. These results suggest that airway operators with the most experience at performing COVID-19 tracheal intubations would have the greatest success when performing the procedure, and future research could focus on the effect of skills training or simulation in improving success with intubation attempts in COVID-19 patients. Moreover, clinician adaptation to the high-stakes setting, both to patient and operator, as well as increased comfort in personal protective equipment used, may have a role to play.

The wide use of videolaryngoscopy in the management of patients with COVID-19 is both predictable and noteworthy. Debate regarding the safety and efficacy of videolaryngoscopy compared with direct laryngoscopy has continued,²⁹ and there have been calls for universal videolaryngoscopy in critical care settings during the current pandemic.⁷ However, our data did not demonstrate a difference in first-pass success rate, nor was there an association between the use of videolaryngoscopy and transmission of SARS-CoV-2.¹⁴ There may be other outcomes of interest for which videolaryngoscopy may be superior to direct laryngoscopy during airway management of patients with COVID-19 that we are unable to investigate using our dataset and that bear clinical relevance and merit future study, such as differences in the proximity of operators and assistants to the patients' airways, speed of intubation, quality of view obtained, or degree of hypoxia during the procedure.

Table 3. Number of Tracheal Intubation Attempts

Number of Intubation Attempts	No.	%
1	4,017	89.7
2	361	8.1
3	75	1.7
4+	23	0.5

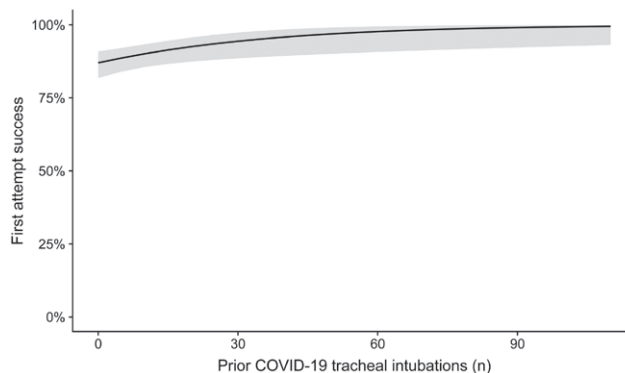


Fig. 4. Plot of the association between the number of previous COVID-19 tracheal intubations before current intubation episode and the likelihood of successfully intubating at first attempt (predicted success computed from the mixed-effects logistic regression model). In this plot, the other model covariates are set to the mean (for numeric variables) or set to their reference level (for categorical variables). The *black line* indicates the prediction estimate for a given number of previous COVID-19 tracheal intubations adjusted for other covariates, and the *gray area* indicates the 95% CI of the prediction estimate.

Table 4. Factors Associated with Success at First Intubation Attempt

		First-attempt Success*	Univariable†		Multivariable‡	
		No. (%) or Mean ± SD	Odds Ratio (95% CI)	P Value	Adjusted Odds Ratio (95% CI)	P Value
Country income status	High-income	3,326 (82.8)	—	0.002	—	0.001
	Low- and middle-income	691 (17.2)	0.59 (0.42–0.82)		0.57 (0.41–0.79)	
COVID-19 status	Confirmed	2,711 (67.5)	—	0.466	—	—
	Suspected	1,306 (32.5)	0.92 (0.73–1.16)		—	
Location	Other hospital location	683 (17.0)	—	0.322	—	—
	Emergency department	690 (17.2)	0.87 (0.61–1.25)		—	
	Intensive care unit	2,544 (63.3)	1.05 (0.77–1.43)		—	
	Operating theater suite	100 (2.5)	0.65 (0.337–1.24)		—	
Indication	Deteriorating respiratory failure	3,606 (89.8)	—	0.064	—	—
	Cardiac arrest	162 (4.0)	0.61 (0.385–0.98)		—	
	Airway protection for low Glasgow Coma Scale	249 (6.2)	0.74 (0.50–1.11)		—	
Rapid sequence induction	No	862 (21.5)	—	< 0.001	—	< 0.001
	Yes	3,155 (78.5)	1.95 (1.53–2.48)		1.89 (1.49–2.39)	
First-attempt device	Direct laryngoscope	982 (24.4)	—	0.027	—	0.050
	Videolaryngoscope	3,029 (75.4)	1.04 (0.79–1.36)		0.87 (0.66–1.14)	
	Fiberoptic intubation	6 (0.1)	0.108 (0.022–0.53)		0.152 (0.033–0.69)	
Operator role	Anesthesiologist	3,295 (82.0)	—	0.106	—	—
	Nonanesthesiologist	722 (18.0)	0.79 (0.60–1.05)		—	
Plastic drape/intubating box used	Not used	3,585 (89.2)	—	0.649	—	—
	Used	432 (10.8)	0.91 (0.60–1.37)		—	
Seniority of operator	Nonconsultant/attending	1,005 (25.0)	—	0.037	—	0.367
	Consultant/attending	3,012 (75.0)	1.33 (1.02–1.74)		1.14 (0.85–1.54)	
Mask	Nonpowered respirator only	3,121 (77.7)	—	0.002	—	0.006
	Powered air-purifying respirator	845 (21.0)	1.72 (1.23–2.39)		1.60 (1.16–2.20)	
	No mask or surgical mask only	51 (1.3)	0.64 (0.291–1.39)		0.62 (0.287–1.33)	
Previous COVID-19 intubations, No.	Mean ± SD (success)	4.1 ± 11.0	1.03 (1.00–1.05)	0.038	1.03 (1.01–1.06)	0.015
	Mean ± SD (failure)	2.2 ± 5.0				
Age of operator (rescaled)§	Mean ± SD (success)	41.8 ± 9.1	1.15 (1.01–1.31)	0.035	1.10 (0.95–1.27)	0.201
	Mean ± SD (failure)	40.5 ± 8.3				

Data are number (percentage), odds ratio (95% CI; P value), or mean ± SD.

*Total number of successful intubations at first attempt (N = 4,017). †For the univariable models, mixed-effects logistic regression models were constructed with a random intercept for operators with each individual variable separately. ‡For the multivariable model, a single mixed-effects logistic regression was constructed with a random intercept for operators with all the variables that were found to be significant in univariable modeling. §For mixed-effects modeling, age was rescaled by centering around the mean and scaled to SD units. ||The mean ± SD for the age of operators is reported unrescaled for ease of interpretation.

While the use of videolaryngoscopy was lower in participating low- and middle-income country sites in our study (50.1%) compared to high-income countries (82.2%), it is likely that resource availability within low- and middle-income countries may be more variable, and our study may have had more participants from better resourced institutions. This could potentially be reflected in the finding that the use of World Health Organization–standard personal protective equipment was greater in low- and middle-income countries than high-income countries.

Tracheal intubation in low- and middle-income countries was associated with a lower likelihood of successful intubation at first attempt. Reasons for this might include variation in the access to resources (equipment and staffing), local differences in intubation criteria and disease severity at the point of presentation to hospital, and other socioeconomic factors that may affect patient access to health care. Additionally, there were other differences between low- and middle-income countries and high-income countries that warrant consideration, including the finding that tracheal intubation was more frequently performed by intensive care doctors, assistance was less frequently provided by trained anesthetic nurses, and there were fewer staff present in the intubation room in low- and middle-income countries. Health systems under stress may exhibit poorer outcomes due to differing demands on available resources. This important hypothesis-generating finding has broad-reaching implications and merits further exploration.

A number of limitations must be highlighted, however. First, the nature of data collection in a self-reported registry may have introduced reporting bias. Second, the countries that participated in the intubateCOVID registry were weighted toward high-income countries, and little data contribution from the Organisation for Economic Co-operation and Development defined Least Developed Countries (those with a gross national income per capita less than or equal to USD\$1,005). Therefore, our findings may not be applicable in the lowest-income countries where healthcare resources are likely to be scarce, and outcomes in patients with severe COVID-19 could be worse. Third, due to its study design, the intubateCOVID registry did not collect some patient-level explanatory variables such as anesthetic drugs used for intubation, patient comorbidities, and physiologic parameters, nor did it collect other relevant patient-level outcomes and complications such as cardiovascular collapse, cardiac arrest, or death at the time of intubation. It is conceivable that illness severity, due to either COVID-19 or underlying medical conditions, may influence physiologic difficulties of tracheal intubation that are unaccounted for in the modeling presented, and potentially catastrophic complications of intubations may have exacerbated reporting bias further as deaths during intubation might result in the intubation procedure being omitted from data collection entirely. Fourth,

there may be residual and unaccounted for confounding between several characteristics of airway management that we observed, in addition to unobserved characteristics. For example, an association between the use of powered air-purifying respirators and successful tracheal intubation may also be affected by the hospital's availability, country, experience level, risk status of the patient, and even the time of day that the tracheal intubation episode took place. Similarly, patients who were expected to be at low risk of airway complications could have been more likely to have received a rapid sequence induction. Moreover, it is possible that there may have been underreporting from emergency department specialists, which could influence the generalizability of our results. Finally, we used a derived variable of the number of previous recorded COVID-19 intubation episodes as a marker of clinician experience in performing tracheal intubation procedures in this setting; however, we cannot be certain that participants in the study recorded all their tracheal intubation episodes consistently in the database, and thus, we may be underestimating the number of previous intubations that an operator might have performed.

Conclusions

Patients with known or suspected COVID-19 experienced higher rates of difficult or failed tracheal intubation, and the requirements for an emergency surgical airway were found when compared to historical reports in the literature. Increased risks of airway complications must be considered when planning to initiate invasive mechanical ventilation in patients with COVID-19 respiratory failure. Optimizing operator factors, such as performing rapid sequence induction, using powered air-purifying respirators, and increased previous COVID-19 tracheal intubation experience, could potentially contribute to successful first-attempt tracheal intubation.

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Competing Interests

Dr. Baker reports a grant from Fisher and Paykel Healthcare (Auckland, New Zealand) and is the owner, manufacturer, and patent holder for the ORSIM Bronchoscopy Simulator (Airway Limited, New Zealand). Dr. Navarro reports consultancy fees from Medcaptain (Shenzhen City, China). The other authors declare no competing interests.

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