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CLINICAL INVESTIGATION

Difficult or impossible facemask ventilation in children with difficult tracheal intubation: a retrospective analysis of the PeDI registry

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Abstract

Background: Difficult facemask ventilation is perilous in children whose tracheas are difficult to intubate. We hypothesised that certain physical characteristics and anaesthetic factors are associated with difficult mask ventilation in paediatric patients who also had difficult tracheal intubation.

Methods: We queried a multicentre registry for children who experienced "difficult" or "impossible" facemask ventilation. Patient and case factors known before mask ventilation attempt were included for consideration in this regularised multivariable regression analysis. Incidence of complications, and frequency and efficacy of rescue placement of a supraglottic airway device were also tabulated. Changes in quality of mask ventilation after injection of a neuromuscular blocking agent were assessed.

Results: The incidence of difficult mask ventilation was 9% (483 of 5453 patients). Infants and patients having increased weight, being less than 5th percentile in weight for age, or having Treacher-Collins syndrome, glossoptosis, or limited mouth opening were more likely to have difficult mask ventilation. Anaesthetic induction using facemask and opioids was associated with decreased risk of difficult mask ventilation. The incidence of complications was significantly higher in patients with "difficult" mask ventilation than in patients without. Rescue placement of a supraglottic airway improved ventilation in 71% (96 of 135) of cases. Administration of neuromuscular blocking agents was more frequently associated with improvement or no change in quality of ventilation than with worsening.

Conclusions: Certain abnormalities on physical examination should increase suspicion of possible difficult facemask ventilation. Rescue use of a supraglottic airway device in children with difficult or impossible mask ventilation should be strongly considered.

Keywords: complications; difficult airway; difficult facemask ventilation; impossible facemask ventilation; paediatrics; supraglottic airway

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Editor's key points

- It is not clear what factors are associated with difficult facemask ventilation in children in whom tracheal intubation was difficult.
- An analysis of a multicentre registry for children with difficult tracheal intubation showed that the incidence of difficult mask ventilation was 9%, and was more likely in infants and patients with increased weight, being less than 5th percentile in weight for age, or having Treacher-Collins syndrome, glossoptosis, or limited mouth opening.
- The study suggests that strategies such as use of a supraglottic airway, or use of a neuromuscular blocking agent can minimise the incidence of difficult mask ventilation.

Effective facemask ventilation is critical for successful airway management.[1] Difficult mask ventilation increases the risk of severe hypoxaemia and adverse events, especially when tracheal intubation is difficult.[2] These issues are further amplified in children because of their smaller functional residual capacity and greater oxygen consumption. Predicting difficult or impossible mask ventilation from a pre-anaesthetic evaluation would be valuable and can guide airway management and the anaesthetic approach.[3,4] In cases where difficult mask ventilation is anticipated, clinicians may choose an awake or sedated approach to secure the airway, prioritising spontaneous ventilation.[5]

Difficult mask ventilation occurs in up to 6% of children.[6,7] Although most children are easy to ventilate using a facemask, the incidence of difficult or impossible mask ventilation becomes higher when tracheal intubation is difficult, with an incidence ranging from 7.6% to 13%.[2,8] Although difficult mask ventilation may occur in a patient without difficult intubation, the consequences are potentially less severe because successful tracheal intubation can restore ventilation. When faced with a patient whose trachea may be difficult to intubate, identifying factors that influence the risk of encountering difficult mask ventilation is important, as it informs the plans for induction of anaesthesia.

Factors associated with difficult mask ventilation have been studied extensively in adults,[6,9–11] but often these risk factors are not applicable to children. There are few studies determining specific features or syndromes associated with difficult mask ventilation in children.

A retrospective review of cases in the Paediatric Difficult Intubation (PeDI) Registry (PeDI), a database of children in whom tracheal intubation was difficult, was conducted to determine the incidence, risk factors, outcomes, and interventions performed when a difficult or impossible ventilation was encountered. We hypothesised that certain physical characteristics and anaesthetic factors are associated with difficult mask ventilation in paediatric patients who also have difficult tracheal intubation. The primary aim of this study was to determine physical characteristics and anaesthetic factors associated with difficult or impossible mask ventilation from patients in the PeDI Registry. A secondary aim of this study was to determine the incidence of complications in children with difficult or impossible mask ventilation and to determine whether these patients had higher incidence of complications relative to patients whose tracheas were difficult to intubate, but were not difficult to ventilate using a facemask. Other secondary aims included determining whether initial difficulty with mask ventilation was worsened or improved after administration of neuromuscular blocking agents and the frequency of use and efficacy of supraglottic airway devices as a "rescue ventilation technique."

Methods

Approval for this retrospective, observational cohort study was granted by a multi-institutional shared agreement as part of the PeDI Registry through the Institutional Review Board (IRB) at the Children's Hospital of Philadelphia. Waiver of consent, parental permission and assent was approved by the IRB for the parent registry. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used in the preparation of this paper.[12]

The PeDI Registry is a multicentre, international registry, created under the auspices of the Society for Pediatric Anaesthesia to prospectively collect data on all paediatric patients where difficult tracheal intubation was encountered.[2] Patients who were difficult to ventilate by facemask but were not difficult tracheal intubations were not included in this registry. Criteria for entry into the registry are described in an earlier publication.[2] Data extracted included cases from September 2011 until August 2021. Thirty-six institutions from seven countries contributed data to the registry during this period, including children's hospitals and hospitals dedicated to the care of both adult and children. Research Electronic Data Capture (REDCap) was used to facilitate standardised data collection across multiple institutions.

Variables that could be known before induction of anaesthesia were included for consideration in this model. The following data elements were extracted: age, weight, sex, American Society of Anesthesiologists (ASA) physical status, emergent status, history of prematurity, location of the case (operating theatre, ICU, emergency department, or other remote location), the presence of an airway-related diagnosis or syndrome, the presence of abnormalities detected by physical examination, the use of opioids, the use of a neuromuscular blocking agent, and induction method of anaesthesia (inhalational or i.v.). Whether a specific set of physical abnormalities and syndromes were present was also extracted (Supplementary Table 1). Percentile weight by age, based upon sex-specific charts from the Centers for Disease Control and Prevention was calculated as a surrogate for BMI.[13] Two binary indicator variables were added to denote whether the patient was below the 5th percentile or above the 95th percentile in weight for age. Data on whether mask ventilation was anticipated to be difficult by the clinician were also collected.

Our primary outcome of difficult or impossible mask ventilation was based on the assessment of the lead clinician supervising the airway management. Patients marked as "difficult facemask ventilation" or "impossible to ventilate by facemask," were combined as a single category of difficult or impossible ventilation, except where specifically mentioned as subcategories. Those marked as 'easy ventilation' or 'ventilation using a facemask performed with an adjunct (a nasal or an oral airway)' were considered easy to ventilate and combined into a single category. Cases where ventilation by facemask was not attempted or the patient had a tracheostomy were excluded from the analysis.

For the secondary analyses, data on the efficacy of supraglottic airways as a rescue device, the quality of mask ventilation after injection of a neuromuscular blocking agent (rated as worsened, unchanged, or improved), and the incidence of study-defined complications[2,14] were also collected. The registry also queries whether difficulty with mask ventilation or laryngoscopy was anticipated. The responses 'anticipated difficult facemask ventilation' and 'anticipated difficult facemask ventilation and laryngoscopy' were counted as prediction of difficult mask ventilation while the responses, 'anticipated difficult laryngoscopy' and 'difficulty was unanticipated' were counted as prediction that mask ventilation would not be difficult.

Amongst the subset of patients reported to be difficult or impossible to ventilate using a facemask, rescue using a supraglottic airway was defined as 'easy placement and ventilation' or 'difficult placement and easy ventilation.' All other responses were considered failure to rescue. The free-text comments included in cases with difficult and impossible mask ventilation were reviewed, and the aetiologies listed were collected for further analysis.

Statistical analysis

The Executive Committee of the PeDI Registry approved of the analysis plans before data access. All analyses were pre-planned, except for the exploration on the aetiology and the incidence of complications in patients with difficult mask ventilation. Medians and interquartile ranges were calculated for continuous data, and the Wilcoxon rank sum test was used to test for differences. Counts and percentages were tabulated for categorical variables. Chi-square and Fisher's exact test and χ^2 test were used to test for differences between categorical variables. Predictor variables with zero variance or near-zero variance were removed. A missingness indicator was added to missing categorical data to allow subject inclusion in the analysis and to maintain statistical power. Because of the high number of variables being considered in the primary analysis, the data were split with 1,193 cases used for Least Absolute Shrinkage and Selection Operator regression to perform variable selection. The remaining 4,260 cases were used to create a multivariable logistic regression model evaluating the association between the selected variables and difficult mask ventilation. The multivariable model evaluated the following independent variables: age group, whether the patient had a weight <5th percentile or >95th percentile, weight, sex, ASA physical status, whether the case was emergent, history of prematurity, presence of identified or unidentified syndromes, induction technique, location, opioid use, and presence or absence of selected craniofacial abnormality. Age and planned ventilation technique were not included in the model because of collinearity with other variables. The Benjamini-Hochberg procedure with false discovery rate set at 5% was used to account for multiple hypothesis testing. No *a priori* sample size calculation was performed because all eligible records were used in this retrospective study, which included 4,970 patients who were easy to ventilate, and 483 who were difficult or impossible to ventilate. Given that sample size, we are adequately powered (>90%) to detect effect sizes as small as 0.15 between groups (two-sample t-test; $\alpha = 0.05$; two-tailed). All statistical analyses were performed using R (version 3.6.3; R Foundation for Statistical Computing, Vienna, Austria.[15] The function "glm()" in the base package[15] was used to create the logistic regression model. The function "glmer()" in the "lme4" package[16] used to create a mixed-effects model. The "vif()" function within "caret"[17] was used to determine the variance inflation factor.

Results

From September 2011 until August 2021, 6,144 cases were enrolled in the PeDI registry. A patient flow diagram is included (Fig 1). A total of 5,453 met the study inclusion criteria. Of these, 4,970 cases reported easy mask ventilation or mask ventilation with an adjunct, such as an oral or a nasal airway. Of the remaining 483 cases, mask ventilation was difficult in 429 cases or impossible in 54 cases. Thus, 9% of patients (483 of 4,970) with known or suspected difficult tracheal intubation were also difficult to ventilate using a facemask. A table of baseline summary statistics is given in Table 1.

Factors associated with difficult mask ventilation

Syndromes where difficult or impossible mask ventilation were most frequently reported include Pierre Robin sequence, Goldenhar, and Treacher Collins. The 10 most frequent syndromes in rank order are presented in Table 2.

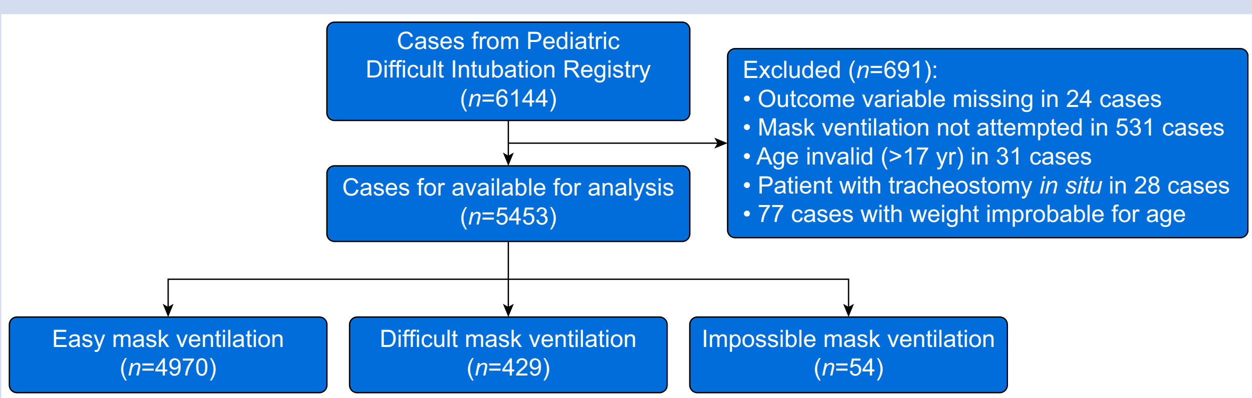


Fig 1. Flow chart of cases used for analysis from the Pediatric Difficult Airway (PeDI) Registry.

Table 1 Patient characteristics and airway management factors in patients from the Pediatric Difficult tracheal intubation (PeDI) registry by the quality of mask ventilation during airway management. CPAP, continuous positive airway pressure; IQR, inter quartile range; N/A, not applicable.

	Difficult ventilation (n=429)	Impossible ventilation (n=54)	Easy mask ventilation (n=4970)
Age, (months), median (IQR)	52 (4–159)	33 (2–131.3)	66 (11–143)
Weight, (kg), median (IQR)	16.7 (5–39.7)	12 (3.1–30.8)	17.1 (7.6–34)
Weight <5th percentile for age, *n* (%)	207 (48%)	21 (39%)	2051 (41%)
Weight >95th percentile for age, *n* (%)	32 (7%)	6 (11%)	236 (5%)
Sex, female, *n* (%)	188 (44%)	24 (44%)	2110 (42%)
ASA physical status, median (IQR)	3 (3–3)	3 (3–4)	3 (2–3)
Emergent case, *n* (%)	54 (13%)	11 (20%)	307 (6%)
Use of a neuromuscular blocking agent, *n* (%)			
Yes	161 (38%)	16 (30%)	2482 (50%)
No	268 (62%)	38 (70%)	2429 (49%)
Ex-premature infant, *n* (%)			
Yes	111 (26%)	14 (26%)	988 (20%)
No	255 (59%)	29 (54%)	3366 (68%)
Unknown	63 (15%)	11 (20%)	616 (12%)
Syndrome, *n* (%)			
Yes	292 (68%)	42 (78%)	3192 (64%)
No	107 (25%)	11 (20%)	1483 (30%)
Unidentified syndrome	30 (7%)	1 (2%)	295 (6%)
Abnormal physical findings, *n* (%)	384 (90%)	51 (94%)	4050 (81%)
Cervical spine (limited mobility or immobility)	78 (18%)	6 (11%)	759 (15%)
Choanalatresia	3 (1%)	1 (2%)	32(1%)
Cleft lip	12 (3%)	3 (6%)	168 (3%)
Cleft palate	62 (14%)	10 (19%)	570 (11%)
Cranio-cervical hardware (halo,etc)	4 (1%)	3 (6%)	80(2%)
Dysmorphism	116 (27%)	15 (28%)	935 (19%)
Facial asymmetry	67 (16%)	10 (19%)	670 (13%)
Facial trauma	6 (1%)	0 (0%)	34 (1%)
Glossoptosis	34 (8%)	6 (11%)	172(3%)
Head/neck mass (tissue expander)	7 (2%)	3 (6%)	97 (2%)
Large occiput	14 (3%)	3 (6%)	134 (3%)
Limited mouth opening	169 (39%)	13 (24%)	1488 (30%)
Macroglossia	48 (11%)	5 (9%)	333 (7%)
Micrognathia	195 (45%)	25 (46%)	1698 (34%)
Microtia	18 (4%)	5 (9%)	266(5%)
Radiated head/neck	1 (0%)	1 (2%)	34 (1%)
Short neck	99 (23%)	7 (13%)	697 (14%)
Temporomandibular joint dysfunction	32 (7%)	1 (2%)	179 (4%)
Upper airway mass	3 (1%)	5 (9%)	65 (1%)
Other	102 (24%)	11 (20%)	979 (20%)
Induction spine-L			
Mask induction	205 (48%)	18 (33%)	2967 (60%)
i.v. induction	189 (44%)	29 (54%)	1892 (38%)
i.v. sedation	22 (5%)	1 (2%)	75 (1.5%)
N/A	13 (3%)	6 (11%)	32 (0.5%)
Unknown	0 (0%)	0 (0%)	4 (0%)
Location			
Operating theatre	371 (86%)	41 (76%)	4534 (91%)
Offsite anaesthesia care	14 (3%)	1 (2%)	241 (5%)
ICU	32 (7%)	6 (11%)	90(2%)
Emergency room	7 (2%)	1 (2%)	27(1%)
Hospital floor	1 (0%)	0 (0%)	15 (0%)
Other	4 (1%)	5 (9%)	63 (1%)
Planned ventilation technique			
Controlled ventilation with a neuromuscular blocking agent	132 (31%)	12 (22%)	2135 (43%)
Controlled ventilation without a neuromuscular blocking agent	102 (24%)	14 (26%)	1487 (30%)
Spontaneous ventilation (with or without CPAP)	195 (45%)	28 (52%)	1347 (27%)
Any opioid used spine-L	187 (44%)	24 (44%)	2628 (53%)

After adjustment for age group, sex, ASA physical status, weight, history of prematurity, and correction for multiple hypothesis testing, patient factors associated with reported difficult or impossible mask ventilation included being an infant, having a weight below the 5th percentile, increasing weight, use of i.v. sedation or i.v. induction for intubation attempt, and tracheal intubation attempt in the ICU (Table 3). Significant craniofacial anomalies included glossoptosis (odds ratio [OR] 2.04; 95% confidence interval (CI): 1.26–3.22) and limited mouth opening (OR 1.5, 95% CI: 1.15–1.98). Treacher Collins syndrome was also significantly associated with difficult or impossible mask ventilation (OR 2.9; 95% CI: 1.55–5.34). Holding other variables constant, opioid administration (OR 0.6; 95% CI: 0.43–0.70) and inhalational inductions (OR 0.7; 95% CI: 0.53–0.88) were inversely associated with difficult or impossible mask ventilation.

Because induction method of anaesthesia and administration of opioids can be influenced by the provider's perception of difficulty with mask ventilation, we investigated the association between the frequency of opioid administration and the frequency of mask induction, with anticipated difficulty with mask ventilation. Opioids were given in 48% (244 of 514) of cases where difficulty with mask ventilation was anticipated and in 49% (1,856 of 3,782) of cases where difficulty was not anticipated. ($P = 0.495$) Likewise, mask induction was chosen 60% (308 of 514) of the time when difficult mask ventilation was expected, whilst it was also chosen 60% (2,278 of 3,782) of the time where difficulty was not expected ($P = 0.892$). These suggest that, on balance, the selection of induction method or whether to administer opioids was not associated with the clinicians' assessment on how difficult mask ventilation would be.

Rescue supraglottic airway

Of 483 cases where difficult or impossible mask ventilation was encountered, placement of a supraglottic airway was attempted in 166 cases (34% of the time). Clinicians attempted placement of a supraglottic airway significantly more often in the setting of impossible mask ventilation (31 of 54 patients [57%]) than difficult mask ventilation (135 of 429 patients [32%], $P<0.001$). Improved ventilation with a supraglottic airway was achieved in 96 of 135 patients (71%) in whom mask ventilation was initially difficult, and in 15 of 31 patients (48%) in whom mask ventilation was initially impossible. The success rate of ventilation via supraglottic airway was significantly lower in patients in whom mask ventilation was initially impossible than in whom mask ventilation was initially difficult ($P = 0.015$).

Effects of neuromuscular blocking agents

Of 429 patients in whom mask ventilation was difficult, data were available on the quality of mask ventilation after injection of a neuromuscular blocking agent in 134 patients (31%). In these patients, injection of a neuromuscular blocking agent improved or did not affect the ease of

Table 2 Syndromes with highest prevalence in patients who experienced difficult or impossible mask ventilation from the Pediatric Difficult Intubation (PeDI) registry. Total number of cases of difficult or impossible mask ventilation from the PeDI Registry was 483. CHARGE, coloboma, heart defects, choanal atresia, retarded growth development, genital anomalies, ear abnormalities; VACTERL, vertebral anomalies, anal atresia, cardiac defects, tracheo-oesophageal CHARGE, coloboma, heart defects, choanal atresia, retarded growth development, genital anomalies, ear abnormalities; VACTERL, vertebral anomalies, anal atresia, cardiac defects, tracheo-oesophageal fistula, renal anomalies, limb anomalies.

Syndrome	Difficult or impossible face mask ventilation (n=483)		Prevalence of difficult mask ventilation within individual syndrome	
	n	%	n	%
Other syndromes	119	24.6%	119/1421	8.4%
Pierre-Robin sequence	72	14.9%	72/597	12.1%
Goldenhar syndrome	36	7.5%	36/379	9.5%
Treacher Collins syndrome	26	5.4%	26/153	17.0%
Klippel-Feil syndrome	9	1.9%	9/102	8.8%
Arthrogryposis	8	1.7%	8/107	7.5%
Hurler syndrome	7	1.5%	7/66	10.6%
Stickler syndrome	7	1.5%	7/55	12.7%
VACTERL syndrome	7	1.5%	7/130	5.4%
22q Deletion	6	1.2%	6/75	8.0%
CHARGE syndrome	6	1.2%	6/92	6.5%
Hunter syndrome	6	1.2%	6/64	9.4%
Noonans syndrome	6	1.2%	6/31	19.4%
Trisomy 18 syndrome	6	1.2%	6/48	12.5%
Moebius syndrome	4	0.8%	4/33	12.1%
Apert syndrome	3	0.6%	3/42	7.1%
Beckwith-Wiedemann syndrome	2	0.4%	2/16	12.5%
Congenital temporomandibular joint dysfunction	2	0.4%	2/9	22.2%
Cystic hygroma	2	0.4%	2/4	50.0%
Freeman-Sheldon syndrome	2	0.4%	2/26	7.7%
Neurofibromatosis	2	0.4%	2/25	8.0%
Trisomy 22 syndrome	2	0.4%	2/16	12.5%
Cornelia de Lange syndrome	1	0.2%	2/29	3.4%
Down syndrome	1	0.2%	1/35	2.9%
Epidermolysis bullosa	1	0.2%	1/61	1.6%
Trisomy 13 syndrome	1	0.2%	1/10	10.0%
Velocardiofacial syndrome	1	0.2%	1/25	4.0%

Table 3 Odds ratios for the association between patient factors and difficult mask ventilation in children with difficult tracheal intubation. ASA, American Society of Anesthesiologists; CHARGE, Coloboma, Heart defects, choanal Atresia, Retarded growth development, Genital anomalies, Ear abnormalities; C-spine, cervical spine; IQR, Interquartile Range; IV, intravenous; N/A, Not Applicable; TMJ, Temporomandibular Joint; VACTERL Syndrome, Vertebral anomalies, Anal atresia, Cardiac defects, Tracheo-Esophageal fistula, Renal anomalies, Limb anomalies.
**Variable significant after Benjamini-Hochberg Procedure with False Discovery Rate of 1%.
*Variable significant after Benjamini-Hochberg Procedure with False Discovery Rate of 5%.
– Variable not considered in final model.

	Odds ratio	95% CI	*p*-value		Adjusted odds ratio	95% CI	*p*-value	
Age group (reference: adolescent)								
Infant	1.09	0.86–1.40	0.474		2.35	1.26–4.42	0.008	*
Toddler	0.59	0.44–0.79	<0.001	**	1.34	0.75–2.42	0.328	
School age	0.58	0.44–0.76	<0.001	**	0.97	0.63–1.50	0.899	
Weight	1.00	1.00–1.01	0.035		1.02	1.01–1.03	0.002	*
Percentile weight								
<5th percentile	1.27	1.05–1.53	0.012	*	1.45	1.10–1.90	0.008	*
>95th percentile	1.71	1.18–2.42	0.003	**	1.71	0.98–2.92	0.053	
Male (reference: female)	0.94	0.78–1.14	0.542		0.94	0.74–1.19	0.599	
ASA physical status	1.60	1.39–1.85	<0.001	**	1.23	1.02–1.49	0.034	
Emergent case	2.36	1.76–3.12	<0.001	**	1.57	1.01–2.36	0.038	
Ex-premature infant	1.50	1.20–1.87	<0.001	**	1.26	0.95–1.66	0.109	
Induction (reference: i.v. induction)								
IV sedation	2.66	1.60–4.27	<0.001	**	1.77	0.85–3.46	0.110	
Mask induction	0.65	0.54–0.79	<0.001	**	0.68	0.53–0.88	0.004	*
Location (reference: operating theatre)								
Emergency room	3.26	1.38–6.90	0.004	**	2.23	0.77–5.85	0.116	
Hospital floor	0.73	0.04–3.63	0.765		–	–	0.968	
ICU	4.65	3.11–6.82	<0.001	**	2.21	1.21–3.91	0.008	*
Offsite anaesthesia care	0.68	0.39–1.12	0.163		0.66	0.34–1.16	0.177	
Other	1.57	0.72–3.02	0.209		0.95	0.22–2.75	0.929	
Opioid administration	0.69	0.57–0.83	<0.001	**	0.55	0.43–0.70	0.000	*
Physical abnormality	2.06	1.53–2.83	<0.001	**	1.14	0.75–1.75	0.560	
C-Spine (limited mobility or immobility)	1.17	0.91–1.49	0.219		1.39	0.98–1.94	0.061	
Cleft lip	0.92	0.51–1.51	0.749		0.70	0.33–1.38	0.321	
Cleft palate	1.35	1.03–1.75	0.026		1.10	0.73–1.65	0.636	
Cranio-cervical hardware (HALO, etc.)	0.90	0.38–1.82	0.788		–	–	–	
Dysmorphism	1.61	1.29–1.98	<0.001	**	1.33	0.99–1.77	0.053	
Facial asymmetry	1.22	0.94–1.56	0.134		–	–	–	
Glossoptosis	2.52	1.74–3.56	<0.001	**	2.04	1.26–3.22	0.003	*
Head/neck mass (tissue expander)	1.06	0.52–1.95	0.858		1.64	0.64–3.64	0.262	
Large occiput	1.32	0.76–2.14	0.294		1.10	0.55–2.04	0.781	
Limited mouth opening	1.41	1.16–1.72	<0.001	**	1.51	1.15–1.98	0.003	*
Macroglossia	1.72	1.25–2.31	0.001	**	1.24	0.82–1.83	0.292	
Micrognathia	1.61	1.33–1.95	<0.001	**	1.15	0.86–1.55	0.351	
Microtia	0.88	0.56–1.34	0.581		0.69	0.37–1.20	0.202	
Short neck	1.72	1.36–2.16	<0.001	**	1.46	1.06–2.00	0.018	
TMJ dysfunction	1.96	1.32–2.84	<0.001	**	1.68	1.01–2.69	0.039	
Upper airway mass	1.27	0.56–2.51	0.526		0.74	0.17–2.27	0.639	
Other physical abnormality	1.25	0.99–1.55	0.053		1.12	0.83–1.50	0.461	
Syndrome	1.32	1.06–1.64	0.014	*	–	–	–	
22q Deletion	0.89	0.34–1.90	0.793		1.67	0.59–3.93	0.277	
Arthrogryposis	0.83	0.37–1.61	2.277		0.58	0.17–1.46	0.303	
CHARGE	0.71	0.28–1.51	0.429		0.57	0.16–1.46	0.295	
Epidermolysis bullosa	0.17	0.01–0.77	0.079		0.40	0.02–1.92	0.373	
Freeman-Sheldon	0.86	0.14–2.90	0.834		–	–	–	
Goldenhar	1.09	0.75–1.53	0.649		1.50	0.91–2.38	0.098	
Hunter	1.07	0.41–2.29	0.883		–	–	–	
Hurler	1.22	0.51–2.52	0.616		–	–	–	
Klippel-Feil	1.00	0.46–1.88	0.990		–	–	–	
Pierre Robin	1.48	1.13–1.92	0.004	**	1.42	0.94–2.11	0.093	
Stickler	1.51	0.62–3.14	0.313		0.60	0.14–1.76	0.411	
Treacher Collins	2.17	1.38–3.29	<0.001	**	2.94	1.55–5.34	0.001	*
VACTERL	0.58	0.24–1.16	0.163		0.57	0.22–1.26	0.206	
Other syndrome	0.92	0.74–1.14	0.456		0.82	0.62–1.07	0.151	

ventilation in 121 of 134 patients (90%) and worsened it in the remaining 13 patients (10%).

In the remaining 54 patients in whom mask ventilation was impossible, data were available on the quality of mask ventilation after injection of a neuromuscular blocking agent in 14 patients (26%). In these patients, injection of a neuromuscular blocking agent improved or did not affect the ease of ventilation in 12 of 14 patients (86%) and worsened it in the remaining two patients (14%). In patients with easy mask ventilation, injection of a neuromuscular blocking agent improved or did not affect ease of ventilation in 1,554 of 1,569 patients (99%), and worsened it in a limited number of patients (the remaining 15 patients [1%]) (Fig 2).

Complications

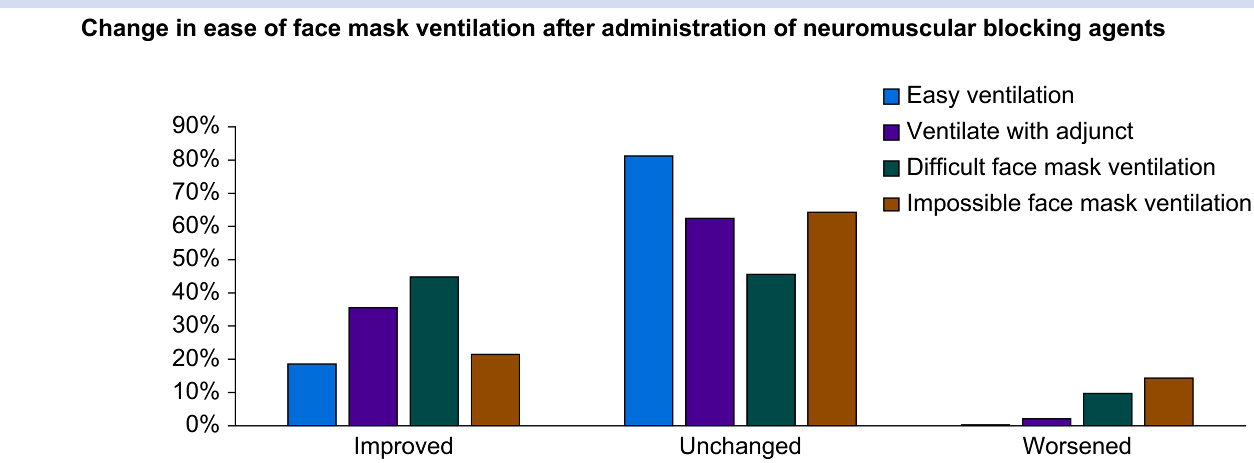
The incidence of complications associated with difficult or impossible mask ventilation (206 of 483 patients [43%]) was significantly higher than those with easy mask ventilation (930 of 4970 patients [19%]; $P < 0.001$). The incidence of complications was even higher in the subgroup of patients with impossible mask ventilation (36 of 54 patients [67%]).

The risks of hypoxaemia, minor airway trauma (26 of 483 patients [5%] vs. 128 of 4,970 patients [3%], $P < 0.001$) and major airway trauma (13 of 483 patients [3%] vs. 26 of 4,970 patients [0.5%], $P < 0.001$) were significantly increased in patients with difficult or impossible mask ventilation compared with patients with easy mask ventilation. The incidence of cardiac arrest was significantly higher, at 14-times the incidence observed in those with easy mask ventilation (28 of 483 patients [6%] compared with 18 of 4,970 patients [0.4%] with easy mask ventilation, $P < 0.001$). A summary of complications by subgroup is presented in Table 4.

The reasons for difficult or impossible mask ventilation could be ascertained from free-text comments in 12 cases. These included poor face mask seal attributable to craniofacial abnormality, masseter spasm or anatomically limited mouth or nares opening preventing placement of an oral or a nasopharyngeal airway, severe tracheal stenosis, patient positioning (where the patient's airway was patent only in a specific head and neck position), airway obstruction attributable to secretions, and light plane of anaesthesia resulting in coughing, bucking, or laryngospasm.

Discussion

We have found that age less than 1 year, <5th percentile weight, increased weight, glossoptosis, and limited mouth opening were some of the physical factors associated with difficult or impossible mask ventilation in patients with difficult tracheal intubation. This adds to previous work demonstrating that children weighing <10 kg experience more airway-related complications.[2,18] Pierre Robin sequence, Goldenhar syndrome, and Treacher Collins were syndromes where difficult or impossible mask ventilation was reported most frequently. After adjustment for multiple factors, Treacher Collins syndrome was independently associated with difficult mask ventilation. Additionally, administration of opioids, and inhalational induction were inversely associated with difficult mask ventilation in this population. We also have found that patients with difficult or impossible mask ventilation had significantly higher incidence of complications



	Improved (*N*=461), *n* (%)	Unchanged (*N*=1226), *n* (%)	Worsened (*N*=30), *n* (%)
Easy ventilation	175 (19)	764 (81)	2 (0)
Ventilate with adjunct	223 (36)	392 (62)	13 (2)
Difficult face mask ventilation	60 (45)	61 (46)	13 (10)
Impossible face mask ventilation	3 (21)	9 (64)	2 (14)

Fig 2. Proportional change in ease of facemask ventilation after administration of neuromuscular blocking agents amongst paediatric patients with known or suspected difficult airway. Ease of ventilation was checked before administration of the neuromuscular blocking agent and reassessed after administration. Clinicians were asked to evaluate if the quality of face-mask ventilation improved, remained unchanged, or has worsened.

Table 4 Complications by level of difficulty with mask ventilation. Grade 1 mask, easy mask ventilation; Grade 2 mask, mask ventilation requiring an oral airway or other adjuvant.

	Difficult mask (n=429), *n* (%)	Impossible mask (n=54), *n* (%)	Mask grade 1 or 2 (n=4970), *n* (%)
Any complication	170 (39.6%)	36 (66.7%)	930 (18.7%)
Minor airway trauma (dental and lip)	24 (5.6%)	2 (3.7%)	128 (2.6%)
Severe airway trauma (glottis, subglottis, palatoglossal arch and intraoral)	8 (1.9%)	5 (9.3%)	26 (0.5%)
Arrhythmia	4 (0.9%)	1 (1.9%)	4 (0.1%)
Aspiration	2 (0.5%)	0 (0%)	3 (0.1%)
Bronchospasm	9 (2.1%)	2 (3.7%)	33 (0.7%)
Cardiac arrest	22 (5.1%)	6 (11.1%)	18 (0.4%)
Death	6 (1.4%)	0 (0%)	6 (0.1%)
Epistaxis	12 (2.8%)	3 (5.6%)	44 (0.9%)
Oesophageal intubation immediately recognised	12 (2.8%)	0 (0%)	113 (2.3%)
Oesophageal intubation delayed recognition	0 (0%)	1 (1.9%)	4 (0.1%)
Hypoxaemia (oxygen saturation < 90% for more than 45 s or 10% decrease in baseline saturation for more than 45 s)	108 (25.2%)	24 (44.4%)	359 (7.2%)
Laryngospasm	21 (4.9%)	7 (13.0%)	79 (1.6%)
Pharyngeal bleeding	18 (4.2%)	5 (9.3%)	90 (1.8%)
Pneumothorax	1 (0.2%)	1 (1.9%)	3 (0.1%)
Vomiting	0 (0%)	0 (0%)	10 (0.2%)
Other	16 (3.7%)	3 (5.6%)	85 (1.7%)

and that injection of a neuromuscular blocking agent either improved or did not affect the ease of mask ventilation the majority of the time. Finally, we have found that supraglottic airways were used in fewer than half of these challenging scenarios but had a reasonable success rate when they were used in patients with difficult mask ventilation.

The incidence of difficult mask ventilation amongst paediatric patients whose tracheas were also difficult to intubate in our study was consistent with previously published data from the PeDI and the Neonate -Children sTudy of Anaesthesia pRactice IN Europe (NECTARINE) registries.[2,8] We have found that patients with difficult or impossible mask ventilation suffered a nearly three-fold increase in complications compared with patients with easy mask ventilation. Knowing about the increased incidence of hypoxaemia, major airway trauma, and cardiac arrest in paediatric patients with difficult mask ventilation, clinicians should be cautious when formulating an airway management plan.

Whether neuromuscular blocking agents should be used or avoided in patients with difficult tracheal intubation has been highly debated. In this study, we have found that neuromuscular blocking agents did not worsen the quality of mask ventilation in most patients who were difficult or impossible to ventilate using a facemask. Clinicians should consider using a neuromuscular blocking agent when appropriate, in cases of functional or mixed functional and anatomic obstruction, keeping in mind ventilation may become worse in some cases. However, the frequency that ventilation improved or remained unchanged was substantially higher than the frequency it worsened in patients who were reported difficult or impossible to ventilate. Consistent with the Difficult Airway Society, European Paediatric Airway Symposium, and ASA guidelines, our data suggest that administration of a neuromuscular blocking agent should be considered when ventilation is impossible.

Most studies in adults report either improvement or no change in mask ventilation after administering a neuromuscular blocking agent,[19–21] even in those with predicted difficult mask ventilation.[21] There are fewer studies and conflicting data in children on the overall benefit of neuromuscular blocking agents in improving mask ventilation. A recent multicentre study from the National Emergency Airway Registry for Children (NEAR4KIDS) has indicated that tracheal intubation without giving a neuromuscular blocking agent is associated with increased frequency of perceived difficult mask ventilation in critically-ill children.[22] In contrast, our findings correlate well with the findings from previous studies on the PeDI Registry, which demonstrated that giving a neuromuscular blocking agent was associated with fewer complications in children with difficult tracheal intubation.[23]

Interestingly, opioid administration was inversely associated with difficult or impossible mask ventilation. Although the underlying mechanism of this association remains unclear, we speculate that opioids may reduce airway reactivity by blunting negative airway reflexes, such as laryngospasm and ventilation dys-synchrony, which may lead to difficult or impossible mask ventilation.[24–26] However, several studies of adult and paediatric patients have indicated that opioids do not reduce the incidence of laryngospasm and may actually cause laryngospasm.[27,28] Further, the clinician must be judicious with dosing in hypotonic children with difficult airways – where ventilation may be worsened by opioids.[29] At high doses, opioids may also lead to stiff chest syndrome,[30] which could result in difficulty with mask ventilation.

There have been few studies comparing inhalational with i.v. induction of anaesthesia.[31–34] We have also found that inhalational inductions were inversely associated with difficult or impossible mask ventilation, compared with i.v. inductions. The rapid loss of airway tone and patency during i.v. inductions that may lead to difficulty with positive-pressure ventilation in susceptible children.[35] Additionally, the more gradual inhalational induction may allow for more stepwise and graded interventions as the patient transitions from spontaneous ventilation to positive-pressure ventilation via a facemask.

The low use of supraglottic airways to improve ventilation in the face of difficult (35%) or even impossible mask ventilation (60%) in our study was surprising, considering that the difficult airway algorithm by the ASA[36] and the Difficult Airway Society guidelines[37] suggest the use of supraglottic airways in these scenarios. Infrequent use of supraglottic airways when difficult mask ventilation was encountered has been reported in other studies.[38,39] Although it is difficult to fully reconstruct the clinical scenario in each situation, it was interesting that supraglottic airways were not attempted with higher frequency. It is possible that difficult ventilation was attributable to a functional obstruction (such as laryngospasm or bronchospasm) that would have been unlikely to resolve with supraglottic airway placement. Although unfortunately being far from universally successful, the clinician should at least attempt to place a supraglottic airway when faced with difficult or impossible mask ventilation, as suggested in the ASA Practice Guidelines for Difficult Airway Management.[36] Furthermore, in our study, supraglottic airway placement improved ventilation in almost 50% situations where impossible ventilation was encountered and more than 70% where ventilation was difficult.

Limitations

There were several limitations to this study. The study population was limited to children with difficult tracheal intubation, who were also difficult or impossible to ventilate using a facemask, limiting generalisability because patients who were difficult to ventilate by facemask, but whose tracheas were not difficult to intubate were not included. Selection bias may have further influenced which cases were entered in the registry. Additionally, because this was a secondary data analysis, inter-rater reliability was not assessed for agreement on presence of physical abnormalities, and the severity of the anatomical abnormalities and whether there had been surgical correction could not be assessed. Another limitation of this study was the small number of patients in whom mask ventilation was impossible. Finally, a large proportion of patients in both the difficult and impossible to ventilate groups have missing data on the use of neuromuscular blocking agent, which may have impacted this analysis.

Conclusions

Physical factors associated with difficult or impossible mask ventilation in these children include being an infant, weight below the 5th percentile, increased weight, glossoptosis, and limited mouth opening. The use of opioids and induction of anaesthesia via facemask appeared was to be inversely associated with difficult or impossible mask ventilation. Further, children who were difficult to ventilate by facemask and whose tracheas were difficult to intubate appear to be at higher risk of complications including hypoxaemia, airway trauma, and cardiac arrest. When difficult or impossible mask ventilation is encountered, supraglottic airway use may be beneficial.

Authors' contributions

Data analysis: LKL
Data interpretation: all authors
Preparation of paper: all authors
Approval of the final paper: all authors.

Declarations of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2023.02.035.

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