ANESTHESIOLOGY

Assessment of Common Criteria for Awake Extubation in Infants and Young Children

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Anesthesiology 2019; 131:801–8

ABSTRACT

Background: Practice patterns surrounding awake extubation of pediatric surgical patients remain largely undocumented. This study assessed the value of commonly used predictors of fitness for extubation to determine which were most salient in predicting successful extubation following emergence from general anesthesia with a volatile anesthetic in young children.

Methods: This prospective, observational study was performed in 600 children from 0 to 7 yr of age. The presence or absence of nine commonly used extubation criteria in children were recorded at the time of extubation including: facial grimace, eye opening, low end-tidal anesthetic concentration, spontaneous tidal volume greater than 5 ml/kg, conjugate gaze, purposeful movement, movement other than coughing, laryngeal stimulation test, and oxygen saturation. Extubations were graded as Successful, Intervention Required, or Major Intervention Required using a standard set of criteria. The Intervention Required and Major Intervention Required outcomes were combined as a single outcome for analysis of predictors of success.

Results: Successful extubation occurred in 92.7% (556 of 600) of cases. Facial grimace odds ratio, 1.93 (95% CI, 1.03 to 3.60; $P = 0.039$), purposeful movement odds ratio, 2.42 (95% CI, 1.14 to 5.12; $P = 0.022$), conjugate gaze odds ratio, 2.10 (95% CI, 1.14 to 4.01; $P = 0.031$), eye opening odds ratio, 4.44 (95% CI, 1.06 to 18.64; $P = 0.042$), and tidal volume greater than 5 ml/kg odds ratio, 2.66 (95% CI, 1.21 to 5.86; $P = 0.015$) were univariately associated with the Successful group. A stepwise increase in any one, in any order, of these five predictors being present, from one out of five and up to five out of five yielded an increasing positive predictive value for successful extubation of 88.3% (95% CI, 82.4 to 94.3), 88.4% (95% CI, 83.5 to 93.3), 96.3% (95% CI, 93.4 to 99.2), 97.4% (95% CI, 94.4 to 100), and 100% (95% CI, 90 to 100).

Conclusions: Conjugate gaze, facial grimace, eye opening, purposeful movement, and tidal volume greater than 5 ml/kg were each individually associated with extubation success in pediatric surgical patients after volatile anesthetic. Further, the use of a multifactorial approach using these predictors, may lead to a more rational and robust approach to successful awake extubation.

(Anesthesiology 2019; 131:801–8)

EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Emergence from anesthesia and extubation is a critical time in pediatric anesthesia when there is an increased risk of adverse events
- Complications are more likely if extubation occurs prematurely during light anesthesia
- Predictors of successful extubation have been identified in critically unwell children and in the intensive care environment but these predictors have related to presence of ongoing cardiopulmonary embarrassment rather than judgement of appropriate plane of anesthesia

What This Article Tells Us That Is New

- For an awake-extubation in a child that has had volatile anesthesia, facial grimace, purposeful movement, conjugate gaze, eye opening, and tidal volume greater than 5 ml/kg are all associated with successful extubation
- The chances of successful extubation steadily increase as more of these features are present

Induction and emergence remain two of the most critical times when caring for pediatric patients because of the increased risk of adverse events at these points of transition.[1–4] Interestingly, routine practice patterns surrounding awake extubation in children remain largely undocumented, and there exist few, if any studies to guide the clinician in managing awake extubation in pediatric patients following general anesthesia.

Most studies looking at predictors of successful extubation in children, defined as extubation without the need for prompt intervention or reintubation, have been retrospective cohort analyses of patients undergoing high-risk procedures such as cardiac surgery or liver transplantation.[5–7] Typically, these studies have centered around procedure-specific factors such as bypass time and amount of blood products transfused rather than more routine

This article is featured in "This Month in Anesthesiology," page 1A. This article is accompanied by an editorial on p. 769. This article has a visual abstract available in the online version.

Submitted for publication December 27, 2018. Accepted for publication June 3, 2019. From the Department of Anesthesiology (T.W.T., E.J.G-D., M.G.D., T.E.S., L.B.T., S.H.P., D.E.H., J.J.O'B., D.H.M, A.E.L., P.R.T., D.G.R.); and the Department of Biostatistics and Data Science (C.J.M.), Wake Forest School of Medicine, Winston-Salem, North Carolina. Current affiliation for D.H.M. is the Edward Via College of Osteopathic Medicine, Spartanburg, South Carolina.

behavioral characteristics like eye opening or inhalation anesthetic level. Numerous other studies have focused on extubation in children in the neonatal or pediatric intensive care unit.[8–10] In all of these studies though, failure is most often a result of ongoing cardiopulmonary embarrassment and not simply a miscalculation of anesthetic depth at extubation. As a consequence, any insights garnered from them are likely to be of limited value in the setting of routine extubation in the operating room.

In more routine settings, the extubation criteria used by clinicians can vary significantly and frequently reflect experience and training bias. Some clinicians have attempted to reduce the complexity of evaluating the timing of extubation by either extubating patients deep or deferring this decision to the recovery room. However, the clinician's ability to correctly judge the optimal time to extubate a pediatric patient awake following inhalational anesthesia still remains essential.[11–13] Commonly used criteria for awake extubation in children include: eye opening, facial grimace, movement other than coughing, purposeful movement, conjugate gaze, and end tidal anesthetic concentration below a predetermined level.[14–16] Other criteria include adequate oxygenation, reversal of neuromuscular blockade, and the laryngeal stimulation test. A positive laryngeal stimulation test is defined as a return to spontaneous ventilation in less than 5 s after gentle stimulation of the glottis by cephalad, caudad motion of the endotracheal tube in a patient ventilating spontaneously at emergence, and is an indicator that the patient may have passed through stage 2 and is ready to be extubated.[4]

At this point, most, if not all, of these criteria have not been validated beyond anecdotal experience, and it is unclear which, if any, is of greater importance as patients transition from deeper to lighter levels of inhalational anesthesia. Therefore, we performed a prospective, observational study to evaluate routine practice and the predictive value of various extubation criteria with the assertion that random overlap and variance in different clinicians' practice would allow us to determine which factors individually or collectively are most important in the awake extubation of young pediatric patients emerging from inhalational anesthesia.

Materials and Methods

After Institutional Review Board approval, we prospectively observed 600 pediatric awake extubations during the course of 10 months at our institution. Our institution is an academic tertiary care pediatric center where all pediatric surgical subspecialties are represented. All extubations were supervised by an attending anesthesiologist. All attendings except one were pediatric fellowship trained, and hailed from seven different training institutions in the United States, creating a diversity of training biases. The one attending that was not fellowship trained completed a pediatric cardiology fellowship and anesthesia residency, but not a pediatric anesthesia fellowship, and has routinely cared for pediatric patients for more than 20 yr. Predictors of successful extubation that were used are summarized in table 1 and were chosen based on the opinion and routine practice of the nine pediatric anesthesiologists in our group. Further, we assumed that all nine attending anesthesiologists at our institution would potentially use different criteria based on their training bias or experience, with some attendings potentially choosing to use certain criteria in preference to others with attendant differences in successful extubation.

Table 1. Catalogue of Predictors of Successful Extubation in Pediatric Patients Less than 7 Yr of Age Observed in This Study

1. Eye opening
2. Facial grimace
3. Patient movement other than coughing
4. Conjugate gaze
5. Purposeful movement
6. End tidal anesthetic less than:
   - Sevoflurane: 0.2%
   - Isoflurane: 0.15%
   - Desflurane: 1.0%
7. Oxygen saturation greater than 97%
8. Positive laryngeal stimulation test
9. Tidal volume greater than 5 ml/kg

Patients older than 7 yr of age were excluded, as were patients with a known difficult airway, tracheostomy *in situ*, patients anticipated to require postoperative mechanical ventilatory support immediately after their surgical procedure, and patients undergoing deep extubation. Deep extubation was defined as any extubation where the intent of the attending clinician was to extubate the patient at a deep plane of inhalational anesthesia where the patient's airway reflexes have been ablated. Patients who underwent total intravenous anesthesia, were maintained on propofol after inhalation induction, or who received a bolus dose of propofol electively before extubation were also excluded. Patients intubated with a nasotracheal tube were excluded due to potential issues of nasal bleeding and other known issues associated with a nasal endotracheal tube that might potentially confound or distort the data set. Emergency cases were not excluded so long as they did not meet other exclusionary criteria. To ensure some degree of randomness in age and case selection, we attempted to capture as many consecutive cases as were available on a given day, but we were limited in some cases by availability of a research assistant or other demands extant in the continued delivery of care at our institution. All cases observed were performed during the normal operating room day schedule Monday through Friday from 7:00 to 18:00. We recorded demographic information on all patients including age, gender, weight, American Society of Anesthesiologists physical class status, and type of surgery. We also recorded the presence of an upper respiratory tract infection. An upper respiratory tract infection was defined as any upper respiratory tract infection symptom including cough, cold, nasal drainage (clear or otherwise), and/or associated fever within the past 7 days by observation on the day of surgery or parental history. The use of midazolam premedication and the presence or absence of asthma were also recorded.

At the time of emergence and extubation, an independent observer not directly involved in the care of the patient recorded the presence or absence of all nine of the extubation criteria evaluated in the study. Tidal volumes were recorded directly from the anesthesia ventilator. The Aestiva (GE Healthcare, USA) and Perseus (Drager, Germany) anesthesia work stations were used for all patients. End tidal anesthetic levels and end tidal carbon dioxide (ET_{CO_2}) were measured using the GE gas analyzer module E-CAI0V-00 (GE Healthcare) or the gas analysis module on the Perseus anesthesia work station. The highest measurement of ET_{CO_2} within 10 s of extubation was recorded. Following extubation, the patient was assessed and the extubation was graded based on specific criteria and was assigned a value of successful, intervention required, or major intervention required. Criteria for each group are summarized in table 2. The intervention groups (intervention required and major intervention required) were combined for analysis *a priori*. The criteria chosen for the successful, intervention required, and major intervention required groups were selected in an attempt to reflect clinically relevant events and outcomes.

Statistical Methods and Sample Size

Not knowing what the event rate would be, we chose an initial sample size of 300 patients to create a multivariable logistic regression model with seven predictors. To ensure sufficient statistical power, we conducted an *a priori* interim analysis of event rates over the first 4 months of the study. This yielded a combined event rate of 6.9%. Given this event rate, we used the rule of 10 events per predictor variable in a logistic regression to revise the sample size and reduced the number of potential predictor variables to be included in the model to four. Given this, we estimated that a sample size of 580 would be necessary (40/0.069 = 580 observations).[17,18] Rounding up, we decided on a final sample size of 600.

Descriptive statistics were performed on all data, and between group differences for successful *versus* "intervention required" extubation were compared using two tailed, two sample, independent *t* tests for continuous and chi-square tests for categorical variables or Fisher exact tests if expected cell counts were fewer than five. The normality assumption within each group was assessed using both the Shapiro–Wilks test and by visually inspecting histograms or Q-Q plots, and all variables analyzed with *t* tests were verified to have met this assumption. An initial positive predictive value and odds ratio for success using a chi-square analysis was performed for each of the nine predictors with $P < 0.05$ considered significant. Variables that had a bivariate significant relationship with successful extubation were then entered into a multiple logistic regression model. The multiple logistic regression model resulted in complete separation of the data points, where the collection of predictors were perfectly able to separate the outcome groups. When complete separation occurs, maximum likelihood estimates do not exist, and thus, odds ratios cannot be calculated. As a result, the multiple logistic regression results are not presented. Finally, the number of bivariate significant predictors present was totaled for each individual, and the relationship between the number of positive predictors and successful extubation was assessed.

Univariate chi-square analysis was also performed on the impact of upper respiratory tract infection, asthma, midazolam premedication in children 1 yr of age or older, inhalation anesthetic choice, age less than 1 yr of age, use of nondepolarizing neuromuscular blocker, and airway procedure on unsuccessful extubation. In looking at the association of premedication with midazolam with the intervention required plus major intervention required group, we chose to analyze only patients older than 1 yr of age as the rate of premedication with midazolam in children less than 1 yr at our institution is exceedingly small

Table 2. Summary of Criteria for Grading Extubation

Successful	Intervention Required	Major Intervention Required
No oxygen desaturation less than 92% or if the patient does desaturate it is for less than 30 s Patient requires CPAP with 100% oxygen for less than 30 s.	Oxygen desaturation less than 92% for greater than 30 s, but less than 1 min Patient requires CPAP with 100% oxygen for greater than 30 s, but less than 2 min. Patient has inspiratory stridor, but this does not lead to desaturation for greater than 1 min or intervention beyond CPAP with 100% oxygen for less than 2 min.	Oxygen desaturation less than 92% for greater than 1 min Patient requires CPAP with 100% oxygen for greater than 2 min. Laryngospasm occurred according to attending clinician. Urgent or emergent administration of propofol or succinylcholine after extubation Breath holding or apnea for greater than 10 s Reintubation

Patients having any one of the criteria will be assigned to the greatest intervention outcome based on independent observation of that patient's extubation.
CPAP, continuous positive airway pressure.

and not comparable to its fairly routine clinical use in children 1 yr of age or older. Lastly, a separate *post hoc* analysis of ET_{CO_2} and its association with the intervention required plus major intervention required group was performed.

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., USA).

Results

Patients

We observed 600 extubations in children between the ages of 0 and 7 yr of age. A summary of the types and prevalence of surgical procedures are presented in table 3 with the most common cases being general surgery (154 of 600 [25.6%]), airway surgery (139 of 600 [23.1%]), and urologic cases (116 of 600 [19.3%]). All patients received intravenous intraoperative opioids. The dose and type were administered according to the routine practice of the clinicians caring for a given patient and were not dictated by the study protocol. There were no missing data points for any patient.

Primary Results

The rate of successful extubation was 92.7% (556 of 600). The combined rate of extubations requiring intervention was 7.3% ([44 of 600] intervention required plus major intervention required): intervention required, 4.8% (29 of 600) plus major intervention required, 2.5% (15 of 600). A univariate, chi-square analysis of eight predictors and Fisher exact analysis of the remaining predictor used in the study yielded five predictors which were significantly associated with extubation success (table 4). These predictors were facial grimace (odds ratio, 1.93 [95% CI, 1.03 to 3.60]; $P = 0.039$); purposeful movement (odds ratio, 2.42 [95% CI, 1.14 to 5.12]; $P = 0.022$), conjugate gaze (odds ratio, 2.10 [95% CI, 1.14 to 4.01]; $P = 0.031$), eye opening (odds ratio, 4.44 [95% CI, 1.06 to 18.64]; $P = 0.042$), and tidal volume greater than 5 ml/kg (odds ratio, 2.66 [95% CI, 1.21 to 5.86]; $P = 0.015$). Additionally, a stepwise increase in any one of these five predictors in any order being present, from one out of five, up to five out of five yielded an increasing positive predictive value for successful extubation of 88.3% (95% CI, 82.4 to 94.3), 88.4% (95% CI, 83.5 to 93.3), 96.3% (95% CI, 93.4 to 99.2), 97.4% (95% CI, 94.4 to 100), and 100.0% (95% CI, 90 to 100) (table 5).

The most prevalent criteria leading to rating an extubation as major intervention required was breath-holding or apnea for greater than 10 s (12 of 15 [80.0%]). Laryngospasm or continuous positive airway pressure for greater than 2 min were the next most prevalent with both present in 11 of 15 (73.3%) patients, with these last two overlapping in 7 of 11 (63.6%) patients. Of the 29 patients requiring intervention, but not requiring a major intervention, 28 of 29 (96.6%) required continuous positive airway pressure longer than 30 s and less than 2 min; 17 of 29 (58.6%) had Sp_{O_2} less than 92% for 30 s to 1 min; and 7 of 29 (34.5%) had stridor not progressing to desaturation for more than 1 min or requiring intervention beyond continuous positive airway pressure with 100% oxygen for less than 2 min. No patients whose extubation was rated as intervention required had only stridor.

Secondary Results

There was no significant difference observed between those extubations requiring intervention (intervention required plus major intervention required) and those that were considered successful in terms of age, weight, American Society of Anesthesiologists status, or gender. A univariate analysis found upper respiratory tract infection and midazolam premedication in children 1 yr of age or older to be associated with extubations requiring intervention (intervention required plus major intervention required: odds ratio, 2.57 [(95% CI, 1.29 to 5.13); $P = 0.007$] and odds ratio, 2.83 [(95% CI, 1.06 to 7.60); $P = 0.031$]), respectively. Upper respiratory tract infection, as defined by the study, was noted in 15.2% (91 of 600) of patients. Additionally, an analysis of ET_{CO_2} at extubation revealed an association with the intervention required plus major intervention required group in patients extubated with an ET_{CO_2} greater than 55

Table 3. Summary of Types of Procedures and Prevalence in Patients Extubated Successfully and Those Requiring Intervention

Type of Surgical Procedure N = 600	Number of Procedures for Each Type of Surgery (%)	Number of Patients with Successful Extubation (%) N = 556	Number of Patients Requiring Intervention (%) N = 44
Airway procedures	139 (23.1)	130 (23.4)	9 (20.4)
Plastics and head and neck surgery not involving the airway	58 (9.7)	53 (9.7)	5 (9.1)
Orthopedic	61 (10.1)	56 (10.1)	5 (11.4)
General surgery	154 (25.6)	144 (25.9)	10 (22.7)
Urology	116 (19.3)	109 (19.6)	7 (15.9)
Ophthalmology	10 (1.7)	9 (1.6)	1 (2.3)
Neurosurgery	24 (4.0)	23 (4.1)	1 (2.3)
Other	38 (6.3)	32 (5.8)	6 (13.6)

Table 4. Prevalence, Positive Predictive Value, and Univariate Chi-square or Fisher Exact Analysis of Nine Commonly Used Predictors of Extubation Success in Pediatric Surgical Patients

Predictor of Successful Extubation	Prevalence of Predictor with Successful Extubation	Positive Predictive Value	95% CI of Positive Predictive Value	Odds Ratio for Successful Extubation	95% CI	*P* Value for Chi-square Analysis
Facial grimace	0.56	0.95	0.97–0.92	1.93	1.03–3.60	0.039
Eye opening*	0.17	0.98	0.95–1.00	4.44	1.06–18.64	0.032
Conjugate gaze**	0.63	0.95	0.93–0.97	2.14	1.14–4.01	0.018
Low End Tidal Agent Concentration	0.31	0.93	0.91–0.95	1.07	0.55–2.09	0.848
Purposeful movement	0.37	0.96	0.93–0.99	2.42	1.14–5.12	0.022
Movement Other Than Coughing	0.77	0.92	0.90–0.94	0.85	0.40–1.82	0.677
Positive Laryngeal Stimulation Test†	0.88	0.92	0.90–0.95	0.91	0.47–1.75	0.313
Tidal volume > 5 ml/kg	0.92	0.94	0.91–0.96	2.66	1.21–5.86	0.015
Spo_2 > 97%	0.92	0.93	0.91–0.95	2.05	0.87–4.88	0.102

*Fisher exact test was used instead of chi-square because one of the cell counts was less than 5. **N = 535 because not all attendings checked for conjugate gaze in all patients. †N = 423 because not all attendings chose to check for a positive laryngeal stimulation test

Table 5. Positive Predictive Value of Stepwise Increase in Number of Five Factors Found to Be Significant Using a Univariate Chi-square Analysis for Successful Extubation

Number of Univariate Predictors Present at Extubation Out of a Possible 5	N	Positive Predictive Value (%)	95% CI (%)
1 of 5	112	88.4	82.4–94.3
2 of 5	164	88.4	83.5–93.3
3 of 5	163	96.3	93.4–99.2
4 of 5	114	97.4	94.4–100.0
5 of 5	30	100.0	90–100*

*The lower bound of the 95% CI was calculated using the 1-(3/N) rule for instances in which the event rate is zero.[19]

mmHg (odds ratio, 3.06 [95% CI, 1.60 to 5.83]; *P* = 0.001). Asthma, use of nondepolarizing neuromuscular blocker, maintenance potent inhalational anesthetic choice, airway procedures, age less than 1 yr of age, and emergency case status were not found to be significantly associated with extubations requiring intervention. A summary of these findings is presented in table 6.

Discussion

The primary finding of this study was that among the factors studied to assess fitness for awake extubation following an inhalational anesthetic in children less than 7 yr of age, the most important are facial grimace, eye opening, purposeful movement, tidal volume greater than 5 ml/kg, and conjugate gaze. Further, because no predictor appears to be far superior to another, a stepwise, multifactorial approach is likely to be more useful to the clinician than using one or two favorites, especially given the difference in prevalence of some of these factors at the time of extubation. To put this in more practical terms, at the time of emergence the clinician, for example, may note that conjugate gaze and tidal volume greater than 5 ml/kg are present. If the clinician chooses to extubate at this point, our study would predict a success rate of 88.4%. If, however, the clinician waits for just one more predictor, such as facial grimace or purposeful movement, their probability of success becomes 96.3%. It should be noted, that although the rate of intervention required plus major intervention required events was zero in patients with five out of five of these predictors present, the number of extubations observed in this group (N = 30) was relatively small, and the 0% intervention required plus major intervention required event rate must be evaluated with some caution in this context. Using the 3/N rule for instances in which an event rate is zero and N is the total number of events, the lower bound of the 95% CI is 90%.[19]

One unanticipated finding of this study was that spontaneous tidal volumes greater than 5 ml/kg were associated with success in preference to other criteria we assumed would be more important, such as low end tidal inhalational anesthetic concentration. This may have been because end tidal inhalational anesthetic concentration is an imprecise measure of the concentration of inhalational anesthetic within the central nervous system.[20] Additionally, anesthetic concentration effects could be altered by a complex synergy with various sedatives (such as midazolam and opioids). The most obvious explanation for small tidal volume being a risk was the potential contribution of residual weakness impacting successful extubation. However, no patient requiring intervention was rescued with additional reversal, and neuromuscular blockade was not associated with patients requiring intervention. We theorize that this finding may actually be related to the rapid and shallow pattern of breathing typically associated with light levels of inhalational anesthesia.[21] Thus, inadequate tidal volume

Table 6. Demographics and Univariate Analysis of Risk Factors for the IR+MIR Group

Demographic Factors	S N = 556	IR+MIR N = 44			*P* Value for *t* test comparison of demographic factors for S *versus* IR+MIR
Mean age (years) ± SD	2.5 ± 2.0	2.7 ± 2.1			0.514
Mean weight (kg) ± SD	13.7 ± 7.1	15.8 ± 11.6			0.250
Factors potentially associated with Extubation Requiring Intervention (IR+MIR)	**S (n) (Prevalence %)**	**IR+MIR (n) (Prevalence %)**	**Odds Ratio for IR+MIR**	**95% CI for Odds Ratio for IR+MIR**	***P* Value for Chi-square or Fisher Exact Analysis of Association of Factor and IR+MIR**
ASA Status					
I	148 (26.7%)	10 (22.7%)	0.81	0.39–1.68	0.567
II	282 (50.8%)	25 (56.8%)	1.28	0.69–2.38	0.437
III or IV*	125 (22.5%)	9 (20.5%)	0.89	0.42–1.89	0.754
Male	369 (66.4%)	31 (70.5%)	1.20	0.62–2.36	0.580
Age < 1 yr	191 (34.4%)	15 (34.1%)	1.02	0.53–1.95	0.951
Emergency case status†	14 (2.5%)	1 (2.3%)	0.90	0.12–7.00	1.000
Airway procedure	130 (23.4%)	9 (20.4%)	0.83	0.39–1.78	0.639
URI	78 (14.0%)	13 (29.5%)	2.57	1.29–5.13	0.007
Asthma†	35 (6.3%)	4 (9.1%)	1.54	0.52–4.54	0.513
$ETco_2$ > 55 mmHg	89 (16.0%)	17 (38.6%)	3.06	1.60–5.83	0.001
Use of NMB	191 (34.4%)	19 (43.2%)	1.45	0.78–2.70	0.239
Midazolam‡	232 (62.9%)	24 (82.8%)	2.83	1.06–7.60	0.031
Sevoflurane	310 (51.6%)	19 (43.2%)	0.71	0.38–1.32	0.283
Isoflurane	201 (36.2%)	20 (45.5%)	1.47	0.79–2.73	0.220
Desflurane	68 (12.2%)	5 (11.4%)	0.92	0.35–2.42	0.866

*ASA status III and IV were collapsed because of a 0% prevalence with extubation requiring intervention (IR+MIR) outcome for ASA status equals IV. †Fisher Exact test used because IR+MIR cell count was <5. ‡Total N = 600 for all risk factors for extubation requiring intervention except for midazolam where N = 398 because children < 1 yr of age were excluded from this analysis.

ASA, American Society of Anesthesiologists; $ETco_2$, end-tidal carbon dioxide; IR+MIR, intervention required plus major intervention required; NMB, nondepolarizing neuromuscular blocker; S, successful; URI, upper respiratory tract infection.

may actually be an indicator or surrogate indicator that the patient has not yet passed out of stage 2.

It was also of interest that conjugate gaze achieved significance. In the design phase of the study, a majority of attendings felt that conjugate gaze was potentially suggestive of readiness for extubation, but was at best a secondary predictor and not something they tended to use as a primary measure of readiness. In fact, in 65 of 600 (10.8%) cases, attendings chose not to check for it at all. It would appear, however, that conjugate gaze is a fairly specific indicator that a patient has passed through stage 2.

Eye opening, purposeful movement, and facial grimace were less surprising as these predictors are well known to most clinicians. The one critique of these three predictors though, is that they appear to be fairly late signs of fitness for extubation as indicated by their lower prevalence in those extubated successfully when compared to some other predictors, and waiting for one or more of them may prolong emergence and extubation.

It is important to recognize the occurrence of these factors is dependent on time, and an assessment of which predictor is present can also guide the clinician in determining where the patient is in the emergence process. Although we did not specifically record which predictors occurred in which order, we can infer from the prevalence of these predictors in patients that were extubated successfully, that certain predictors such as tidal volume greater than 5 ml/kg and conjugate gaze are fairly early indicators reflected by their increased prevalence in 92% and 63% of patients extubated successfully, respectively. Further, we can infer that purposeful movement or eye opening are likely to be later signs, presenting in only 37% and 17%, respectively, of patients extubated successfully. In situations where one or more criteria are absent, as not all criteria occur in exactly the same order every time, an evaluation of which of these criteria is present, including those that did not achieve significance, may give additional guidance to the clinician in assessing the risk and timing of extubation. For example, a positive laryngeal stimulation test may be reassuring in a patient with tidal volumes greater than 5 ml/kg and conjugate gaze, with no other criteria present, but by itself, its high prevalence in patients extubated successfully would suggest that it occurs relatively early in the process of emergence and as such the patient may still be at increased risk of laryngospasm.

Now the conservative clinician might suggest that perhaps extubation should be delayed until all five of these predictors are present, as they will all eventually become present with time. While this will likely increase the rate of success slightly, it may be impractical and unnecessary, especially as the time to extubation after completion of surgery becomes unwieldy. Additionally, there appears to be progressively smaller benefit in terms of predictive value when going from three to four or four to five predictors, as compared to going from two to three predictors. In higher risk patients, though, this may represent an appropriate strategy.

Factors that were associated with a lack of success included: upper respiratory tract infection symptom within 7 days of the surgical procedure, midazolam premedication in children greater than 1 yr of age, and *post hoc* an $\mathrm{ETCO_2}$ greater than 55 mmHg. While we cannot say that there is a causal relationship between extubations requiring intervention and these factors, their association with the extubations requiring intervention would suggest that they may alter the predictive value of the five criteria identified in this study individually and/or collectively. As a result, the clinician may want to exercise additional caution at the time of extubation in these settings. Of these three, an $\mathrm{ETCO_2}$ greater than 55 mmHg appeared to have the greatest association with extubations requiring intervention. Obviously, multiple factors, alone and in combination can lead to reduced alveolar ventilation and thus elevations of $\mathrm{ETCO_2}$. Thus, it is difficult to make specific recommendations to the practicing clinician, but this may represent an area for future study. At this time, we are aware of only one study by Baijal *et al.* in children undergoing adenotonsillectomy which specifically mentions the impact of an $\mathrm{ETCO_2}$ greater than 55 mmHg, at the time of extubation, stating that it was only associated with minor respiratory complications in the postanesthesia care unit.[11]

The limitations of this study include its observational design and the fact that it was conducted at a single center. It is possible that practice patterns between attendings were more similar than first appreciated leading to bias and possible confounding with similar criteria being used by different attendings. Additionally, these results do not apply to "awake" removal of a supraglottic airway device or "deep" extubation. The results and possible conclusions of this study also, only apply to cases in which an inhalational anesthetic is used for maintenance and not to cases where propofol or total intravenous anesthesia are used for maintenance. This is because potent inhalational anesthetics have different mechanisms of action and different interactions with reactive airway reflexes.[22] Also, it may be that certain preexisting factors, such as age, upper respiratory tract infection, sleep apnea, as well as the variance in the anesthetic prescription for each patient in terms of types, dose, and timing of various opioids, dexmedetomidine, ketamine, and the use of midazolam, may have significantly affected the value of any one individual criteria and controlling for this may have led to different findings. Finally, it is also possible that another criterion exists that was not included in the study that may actually be more important in terms of predicting extubation success than any one of the criteria we selected.

In conclusion, a multifactorial approach including conjugate gaze, purposeful movement, eye opening, tidal volume greater than 5 ml/kg, and facial grimace may lead to increased rates of successful extubation in young children undergoing anesthesia and surgery. Further, this information may allow the clinician to approach awake extubation in a more rational fashion than was available previously. More prospective study is necessary to further clarify the interactions of other comorbidities such as obesity, upper respiratory tract infection, and sleep disordered breathing on the predictive value of these different criteria.

Acknowledgments

The authors would like to acknowledge Forrest A. Roberson, B.S., East Carolina School of Medicine, Greenville, North Carolina, and Marina Lin, B.S., Department of Anesthesiology, Wake Forest University, Winston-Salem, North Carolina, for assisting with extensive data collection; Addie Larimore, B.A., Department of Anesthesiology, Wake Forest University, for editorial assistance in preparing manuscript; and would like to acknowledge the Study Coordinator Pool, Biostatistics Core, and Regulatory Knowledge & Support Program of the Wake Forest Clinical and Translational Science Institute, which is supported by the National Center for Advancing Translational Sciences, National Institutes of Health (Bethesda, Maryland) through grant No. UL1TR001420.

Research Support

Support was provided solely from institutional and/or departmental resources.

Competing Interests

The authors declare no competing interests.

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