

# Prediction and Outcomes of Impossible Mask Ventilation

## A Review of 50,000 Anesthetics

Sachin Kheterpal, M.D., M.B.A.,\* Lizabeth Martin, M.D.,† Amy M. Shanks, M.S.,‡ Kevin K. Tremper, Ph.D., M.D.§

**Background:** There are no existing data regarding risk factors for impossible mask ventilation and limited data regarding its incidence. The authors sought to determine the incidence, predictors, and outcomes associated with impossible mask ventilation.

**Methods:** The authors performed an observational study over a 4-yr period. For each adult patient undergoing a general anesthetic, preoperative patient characteristics, detailed airway physical exam, and airway outcome data were collected. The primary outcome was impossible mask ventilation defined as the inability to exchange air during bag-mask ventilation attempts, despite multiple providers, airway adjuvants, or neuromuscular blockade. Secondary outcomes included the final, definitive airway management technique and direct laryngoscopy view. The incidence of impossible mask ventilation was calculated. Independent ( $P < 0.05$ ) predictors of impossible mask ventilation were identified by performing a logistic regression full model fit.

**Results:** Over a 4-yr period from 2004 to 2008, 53,041 attempts at mask ventilation were recorded. A total of 77 cases of impossible mask ventilation (0.15%) were observed. Neck radiation changes, male sex, sleep apnea, Mallampati III or IV, and presence of beard were identified as independent predictors. The receiver-operating-characteristic area under the curve for this model was  $0.80 \pm 0.03$ . Nineteen impossible mask ventilation patients (25%) also demonstrated difficult intubation, with 15 being intubated successfully. Twelve patients required an alternative intubation technique, including two surgical airways and two patients who were awakened and underwent successful fiberoptic intubation.

**Conclusions:** Impossible mask ventilation is an infrequent airway event that is associated with difficult intubation. Neck radiation changes represent the most significant clinical predictor of impossible mask ventilation in the patient dataset.

MASK ventilation is an essential component of airway management and serves an important role in the case of difficult intubation.<sup>1</sup> However, despite the large amount of research into the prediction of and outcomes associated with difficult intubation, data on difficult or impossible mask ventilation are limited.<sup>2</sup> In 2006, we reviewed 22,000 anesthetics and observed 313 (1.4%) cases of difficult mask ventilation and 37 (0.16%) cases of impossible mask ventilation.<sup>3</sup> Although we were able to derive a robust prediction scale for difficult mask ventilation, the limited number of observed impossible mask venti-

lation attempts did not offer the statistical power necessary to derive a prediction scale with adequate discriminating capability. We were only able to identify a history of snoring and limited thyromental distance as predictors of impossible mask ventilation. In addition, 17 of the 37 impossible mask ventilation patients did not undergo a complete, robust airway exam including an assessment of jaw protrusion, further reducing the ability to derive a useful prediction scale. Finally, the previous data did not include a detailed, manual review of the anesthesia record to identify the ultimate clinical management of each event. As a result, clinicians still have minimal data to guide their prediction or management of impossible mask ventilation, and the need for further research into impossible mask ventilation persists.<sup>4</sup>

The primary goal of the current study was to fill the void of impossible mask ventilation prediction and management. First, we sought to delineate the airway outcomes and management of a large set of impossible mask ventilation events. Second, we hoped to derive a prediction score that would allow clinicians to better identify patients at high risk for impossible mask ventilation. Given the markedly different incidence of impossible and difficult mask ventilation, we hypothesized that the risk factors for impossible mask ventilation would be distinct from previously published risk factors for difficult mask ventilation.<sup>3,5,6</sup> By expanding the number of events observed, we hoped to achieve the statistical power necessary to derive an effective prediction scale.

## Materials and Methods

University of Michigan (Ann Arbor, Michigan) institutional review board approval was obtained for this observational study. Signed patient consent was waived because no patient care interventions were involved in the conduct of the study, and all protected health information was destroyed after data collection was completed.

All adult patients (age 18 yr or older) undergoing a general anesthetic at our tertiary care university hospital were included over a 4-yr period from 2004 to 2008. All cases without an attempt at mask ventilation were excluded from the data collection and analysis, including planned awake fiberoptic intubations. For each anesthetic case, a detailed anesthesia preoperative history and physical is documented by an anesthesia provider using a perioperative clinical information system (Centricity®, General Electric Healthcare, Waukesha, WI).

\* Assistant Professor, † Resident, ‡ Research Associate, § Robert B. Sweet Professor and Chairman, Department of Anesthesiology, University of Michigan Medical School, Ann Arbor, Michigan.

Received from the Department of Anesthesiology, University of Michigan Medical School, Ann Arbor, Michigan. Submitted for publication September 15, 2008. Accepted for publication December 3, 2008. Support was provided solely from institutional and/or departmental sources.

Address correspondence to Dr. Kheterpal: Department of Anesthesiology, 1H247 Box 0048 University Hospital 1500 East Medical Center Drive, Ann Arbor, MI. sachinkh@med.umich.edu. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.

**Table 1. Preoperative Patient Characteristics**

Risk Factor	Impossible Mask Ventilation Yes (n = 77)	Impossible Mask Ventilation No (n = 52,964)	P Value*	Percent Data Complete
Age, yr†	55 ± 15	51 ± 17	0.04	100.0%
Body Mass Index, kg/m <sup>2</sup> †	31 ± 8	28 ± 6	< 0.001	99.3%
Male sex	61 (79%)	24,323 (46%)	< 0.001	100.0%
Cardiac surgery	8 (11%)	3,248 (6.2%)	0.09	98.6%
Junior anesthesia provider	47 (61%)	25,034 (47%)	0.02	100.0%
Sleep apnea	20 (26%)	3,660 (7.1%)	< 0.001	97.8%
Snoring	28 (37%)	12,894 (25%)	0.02	97.2%
Presence of beard	22 (29%)	5,587 (11%)	< 0.001	97.4%
Unstable cervical spine	1 (1.3%)	195 (0.4%)	0.25	99.4%
Limited neck extension	10 (13%)	4,139 (7.9%)	0.10	99.4%
Edentulous	10 (13%)	3,631 (7.0%)	0.04	97.6%
Thick neck	27 (35%)	6,232 (12%)	< 0.001	97.6%
Neck radiation changes	3 (3.9%)	307 (0.6%)	0.01	97.6%
Limited thyromental distance	10 (13%)	2,955 (5.7%)	0.01	97.7%
Limited jaw protrusion	10 (13%)	4,858 (9.4%)	0.28	97.6%
Severely limited jaw protrusion	0 (0%)	244 (0.5%)	1.00	97.6%
Limited mouth opening	5 (6.5%)	1,891 (3.7%)	0.21	97.8%
Mallampati III or IV	23 (30%)	5,950 (12%)	< 0.001	95.9%

\* All patient characteristics were compared using Mann-Whitney U test for continuous variables and chi-square or Fisher exact test for categorical variables; † Mean ± standard deviation.

This history and physical includes discrete data elements regarding patient anthropomorphic details, airway physical exam information, and other general patient clinical information (table 1, appendix 1). For each discrete data element, a user may easily select from predefined pick lists for each item (appendix 1) or choose to enter free-text information if they feel that the pick-list options do not accurately describe the clinical situation.

Each intraoperative record is documented using the perioperative clinical information system as well. At our institution, clinicians describe the ease or difficulty of mask ventilation in the intraoperative record using a previously described four-point scale (table 2).<sup>7</sup> Grade 4 mask ventilation is synonymous with impossible mask ventilation in this scale. In addition, all other intraoperative clinical documentation regarding direct laryngoscopy view, airway adjuvants, and alternative or advanced airway management techniques is entered into the intraoperative record of the perioperative clinical information system. A detailed airway physical exam with discrete data elements for cervical spine mobility, dentition, neck anatomy, thyromental distance, jaw protrusion, mouth opening, and Mallampati oropharyngeal classification (as modified by Samssoon and Young<sup>8</sup>) is incorporated into the anesthesia history

and physical. Because large-dose opioid induction techniques may be associated with chest wall rigidity or vocal cord closure and mistaken for impossible mask ventilation, cardiac surgery was incorporated as an independent variable.<sup>9</sup> In addition, the experience level of the anesthetist was recorded for each case to assess this as a confounding variable.<sup>10</sup> Interns, non-anesthesiology rotators, Clinical Anesthesia-1, and Clinical Anesthesia-2 residents were defined as “Junior Anesthetists,” and Clinical Anesthesia-3 residents, Anesthesiology Fellows, or Certified Registered Nurse Anesthetists were defined as “Senior Anesthetists.”

The primary outcome was impossible mask ventilation, defined as the inability to establish face-mask ventilation despite multiple airway adjuvants and two-hand mask ventilation. Of note, if mask ventilation is simply “inadequate” despite multiple adjuvants and providers, it is described as Grade 3 (difficult) mask ventilation at our institution (table 2). The use of neuromuscular blockade or the type of blockade (depolarizing or nondepolarizing) does not affect the designation of impossible mask ventilation. Secondary outcomes included the ultimate airway management technique (*i.e.*, direct laryngoscopy, rigid indirect laryngoscopy, flexible fiberoptic intubation, case performed with laryngeal mask airway, patient

**Table 2. Mask Ventilation Scale and Incidence**

Grade	Description	N (%)
1	Ventilated by mask	37,857 (71.3%)
2	Ventilated by mask with oral airway/adjuvant with or without muscle relaxant	13,966 (26.3%)
3	Difficult ventilation (inadequate, unstable, or requiring two providers) with or without muscle relaxant	1,141 (2.2%)
4	Unable to mask ventilate with or without muscle relaxant	77 (0.15%)
	Total cases	53,041

awakened, emergency surgical airway access, etc), grade view of direct laryngoscopy if performed, and number of laryngoscopy attempts. Difficult intubation was defined as a grade III or IV Cormack-Lehane direct laryngoscopy view<sup>11</sup> or more than three attempts at intubation by an anesthesiology attending. For each case of impossible mask ventilation, the entire intraoperative record was individually reviewed by two of the study investigators (SK, LM) to independently confirm the ultimate airway management technique and number of laryngoscopy attempts. In addition, the dose of intravenous sedative-hypnotic agents and the dose of neuromuscular blockade agents administered during anesthesia induction were recorded in mg/kg for each impossible mask ventilation case. These values were compared to commonly accepted induction doses: 1 mg/kg succinylcholine, 0.08 mg/kg vecuronium, 0.1 mg/kg cisatracurium, 1.5–2 mg/kg propofol, 0.2–0.3 mg/kg etomidate, and 3–6 mg/kg thiopental.<sup>12</sup>

Anesthesia services are provided by anesthesiology attending staff with assistance from certified registered nurse anesthetists, anesthesia residents, and fellows-in-training. In general, both mask ventilation and intubation are attempted initially by the anesthesiology resident or certified registered nurse anesthetist present in the room. All clinical decisions regarding airway management are made by the attending staff. The attending could choose to perform an awake fiberoptic intubation at their discretion, thereby eliminating an attempt at mask ventilation. Mask ventilation is generally performed without a harness by using a black rubber reusable mask (Rüsch; Teleflex Medical Inc, Research Triangle Park, NC) or clear disposable plastic mask (King Systems Corporation, Noblesville, IN). Laryngoscopy was performed using a fiberoptic direct laryngoscopy handle and blade (Heine Inc., Dover, NH).

### Statistical Analyses

Statistical analyses were performed using SPSS<sup>®</sup> version 15 (SPSS Inc, Chicago, IL). First, descriptive analyses were performed on all independent variables. The Mann-Whitney U test was performed on nonnormally distributed continuous variables. Simple descriptive analysis of categorical variables was performed with either a chi-square or Fisher exact test.

Next, collinearity diagnostics and Pearson correlations were evaluated for all independent variables listed in table 1. All remaining variables were entered into a logistic regression full model fit with the occurrence of impossible mask ventilation as the dependent dichotomous outcome. All variables deemed to be significant in the full model fit ( $P < 0.05$ ) were established as independent predictors. The resulting model's predictive value was evaluated using a receiver-operating-characteristic area under the curve or

c-statistic. Each independent predictor was assessed for effect size using adjusted odds ratios.

An unweighted risk scale assigning one point to each risk factor was created using the independent risk factors. In addition, a weighted prediction score based on the  $\beta$  coefficient of the independent predictors was derived from the logistic regression model. The weighted points were calculated by taking the specific  $\beta$  coefficient for each independent predictor divided by the lowest  $\beta$  coefficient of all the independent predictors, multiplied by two, and rounded to the nearest integer.<sup>13</sup> Each patient received a weighted risk score based on the sum of the points for each predictor they possessed. The unweighted and weighted prediction score were compared using the c-statistic. Odds ratios were derived for the unweighted risk score.

Based on previous studies demonstrating an impossible mask ventilation incidence of 0.16%,<sup>3</sup> we planned on data collection for approximately 50,000 mask ventilation attempts to observe approximately 80 events. A series describing 80 events would double our previous published dataset on impossible mask ventilation and reduce the impact of logistic regression model overfitting.<sup>3,14</sup>

## Results

Of 94,630 anesthetics performed between 2004 and 2008 at our institution, 53,041 operations included an attempt at mask ventilation. Of these, 77 patients (0.15%) experienced the primary outcome of impossible mask ventilation (table 2), resulting in an incidence of approximately 1 in 690. Of these 77 observed cases, 20 were included in a previous, smaller mask ventilation study.<sup>3</sup>

Of the 77 impossible to ventilate patients, 19 (25%) also demonstrated difficult intubation, and 15 of these patients were successfully intubated. Overall, 4 of the 77 patients were not intubated. In six cases, the anesthesiologist attempted to use a disposable, nonintubating laryngeal mask airway as a temporizing measure. Twelve patients required an alternative intubation technique, including two surgical airways and two patients who were awakened for a successful flexible fiberoptic intubation. Complete details are available in table 3. Of note, all but 4 of the 77 impossible mask ventilation patients received neuromuscular blockade in the process of induction or management of the airway, with succinylcholine being used in 65 cases and a nondepolarizing agent in 8 of the cases. A variety of intravenous induction agents were used, with propofol and thiopental representing the majority. In all cases, the dose of neuromuscular blockade and intravenous induction agent were sufficient when compared to weight-based clinical recommendations (data not shown).

**Table 3. Airway Outcomes in Cases of Impossible Mask Ventilation**

Description	Count
Intubated without difficulty (grade I or II direct laryngoscopy view and no more than three attempts)	58
Intubated with difficulty using direct laryngoscopy (grade III or IV direct laryngoscopy view or at least four attempts)	8
Intubated with difficulty using McCoy blade for direct laryngoscopy	2
Intubated using rigid indirect laryngoscopy (e.g., Bullard, Glidescope)	4
Intubated using blind lightwand	1
Patient woken, subsequent awake fiberoptic intubation	2
Patient woken, subsequent awake tracheostomy by surgical team	1
Emergent cricothyrotomy	1
Total	77

Collinearity diagnostics did not demonstrate any condition indices over 30. All the variables listed in table 1 were entered into a logistic regression full model fit with impossible mask ventilation as the dependent dichotomous variable. The logistic regression model included 47,976 patients (91%) and demonstrated 5 independent predictors of impossible mask ventilation ( $P < 0.05$ ): neck radiation changes, male sex, sleep apnea, Mallampati III or IV, and presence of beard (table 4). The omnibus test of model coefficients demonstrated a chi-square value of 103.901 with 18 degrees of freedom and  $P < 0.001$ . The model's c-statistic was  $0.80 \pm 0.03$  (fig. 1). Adjusted odds ratios are reported for each predictor (table 4).

Weighted and unweighted models were created on the basis of the five independent predictors. The weighted model demonstrated a c-statistic of  $0.76 \pm 0.03$ , and the unweighted model demonstrated a c-statistic of  $0.75 \pm 0.03$ . The unweighted risk scale was used for subsequent analysis because of ease of use. Patients with one or more, two or more, three or more risk factors, and four or more risk factors were compared to patients with zero risk factors to assess the odds ratio associated with each degree of risk (fig. 2). Of note, patients with three or more risk factors demonstrated an odds ratio of 8.9 when compared with patients with no risk factors for impossible mask ventilation.

## Discussion

Our data demonstrate that impossible mask ventilation is an infrequent event, occurring approximately once in

every 690 cases. Impossible mask ventilation often requires advanced airway management techniques. One-quarter of impossible to ventilate patients are also difficult to intubate (19 of 77), resulting in an overall incidence of 1 in every 2,800 cases. Our data demonstrate that providers use a variety of techniques when confronted with impossible mask ventilation, ranging from conservative approaches such as attempting to wake up the patient for an awake fiberoptic intubation to immediately proceeding with airway adjuvants such as the lightwand. We have also created the first risk scale for predicting impossible mask ventilation, identifying neck radiation changes as the most significant predictor of impossible mask ventilation.

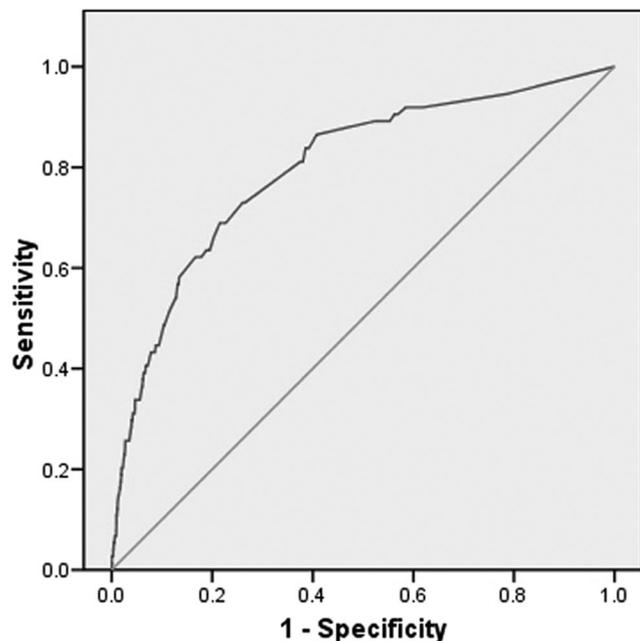
There are limited existing data evaluating mask ventilation as a primary airway outcome.<sup>15</sup> We are able to confirm that impossible mask ventilation is an infrequent event, with an incidence of 0.15% in the studied tertiary care center population (table 2). This is consistent with data published previously from our center, which found the incidence to be 0.16%.<sup>3</sup> Unfortunately, the only other reports of impossible mask ventilation in the literature are limited to case reports or single events in smaller studies, making incidence comparisons to other centers difficult.<sup>5,6,16</sup> Langeron *et al.* observed one episode of impossible mask ventilation in 1,502 prospectively analyzed patients. Unlike the study of difficult mask ventilation, impossible mask ventilation offers a more consistent definition and may allow for comparison across centers.<sup>2,4</sup> Further multicenter research is necessary in order to confirm our observed incidence.

**Table 4. Independent Predictors of Impossible Mask Ventilation**

Predictor	$\beta$ Coefficient	Standard Error	P Value	Weighted Points*	Adjusted Hazard Ratio (95% Confidence Interval)
Neck radiation changes	1.964	0.628	0.002	6	7.1 (2.1–24.4)
Male sex	1.206	0.322	< 0.001	4	3.3 (1.8–6.3)
Sleep apnea	0.859	0.302	0.005	3	2.4 (1.3–4.3)
Mallampati III or IV	0.678	0.276	0.014	2	2.0 (1.1–3.4)
Presence of beard	0.639	0.284	0.024	2	1.9 (1.1–3.3)

Independent predictors of impossible mask ventilation were derived using a logistic regression full model fit.

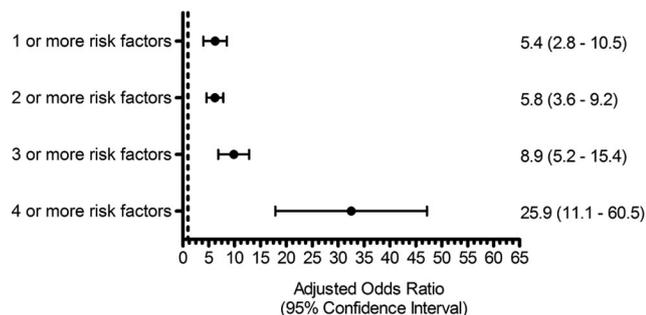
\* Points in the weighted score were assigned to each risk factor by dividing each  $\beta$  coefficient by the smallest  $\beta$  coefficient of the independent predictors, multiplying by two, and rounding to the nearest integer.



**Fig. 1.** A receiver-operating-characteristic curve evaluating the sensitivity and specificity of preoperative independent risk factors for impossible mask ventilation is demonstrated. Five independent predictors of impossible mask ventilation were identified using a logistic regression full model fit ( $P < 0.05$ ): neck radiation changes, male sex, sleep apnea, Mallampati III or IV, and presence of beard.

The weighted receiver-operating-characteristic curve is based on the predicted probability calculated for each patient using the logistic regression full model fit. The curve assists practitioners in evaluating the value of a test. The c-statistic for the full model fit was  $0.80 \pm 0.03$ .

The American Society of Anesthesiologists difficult airway algorithm offers guidance regarding the difficult to intubate patient.<sup>1</sup> Unfortunately, it does not indicate how to manage a patient who is difficult or impossible to mask ventilate before tracheal intubation attempts. As a result, a variety of clinical responses to impossible mask ventilation have come into favor with little data or evidence to support them.<sup>4</sup> Our description of the final airway outcome in the 77 patients experiencing impossible mask ventilation is the first large case series in the



**Fig. 2.** Impossible mask ventilation risk factors and adjusted hazard ratios. Five independent predictors of impossible mask ventilation were identified using a logistic regression full model fit. Patients with one, two, three, or four or more risk factors were compared to patients with exactly zero risk factors to determine a hazard ratio ( $\pm 95\%$  confidence interval) based on the number of risk factors.

published literature. These hypothesis-generating data can serve as the foundation for future research and recommendations into the management of impossible mask ventilation. These data may undermine some anesthesiologist's practice of awakening a patient or avoiding neuromuscular blockade in the case of impossible mask ventilation.<sup>4</sup> Our observation that 25% of impossible to ventilate patients were also difficult to intubate should raise significant concern. The scenario of impossible mask ventilation combined with difficult intubation represents a worst-case scenario.

However, because our study was observational in nature and did not mandate any care protocols or specific interventions, we cannot offer concrete guidance on the management of impossible mask ventilation. The variety of responses, ranging from no neuromuscular blockade to the use of intermediate-duration nondepolarizing agents, demonstrates that several strategies could be successful. More importantly, there are specific airway details regarding each patient that may warrant further study and analysis.

Our data also offer the first prediction scale for impossible mask ventilation. We have identified five independent predictors of impossible mask ventilation: neck radiation changes, male sex, sleep apnea, Mallampati III or IV, and presence of beard. In addition to offering statistical significance, the adjusted odds ratios for each risk factor are also clinically significant (table 4). Some of these risk factors overlap with previously described risk factors for difficult intubation or difficult (yet possible) mask ventilation.<sup>3,5,16</sup> Of note, the presence of a beard was previously observed to be associated with difficult mask ventilation, but not impossible mask ventilation.<sup>3,5</sup> We can hypothesize that the difficult to achieve mask fit, when combined with other predisposing factors, results in impossible mask ventilation. The role of oropharyngeal disproportion, sleep apnea, and male sex as predisposing factors for airway collapse is well established.<sup>3,5,6</sup> Of note, certain features such as obesity, snoring, and lack of teeth, which have been previously noted to be associated with difficult mask ventilation, were not associated with impossible mask ventilation in our data. We can speculate that these features may increase the challenge of maintaining airway patency, but they can be overcome with maneuvers such as a jaw thrust or oral airway.<sup>1,6,17-23</sup> Although all of the patients possessing a beard were male, each of these possibly overlapping characteristics were observed to be independent predictors using a multivariate regression model. This would suggest that male sex itself is a risk factor, with or without presence of a beard.

The presence of neck radiation changes has not been previously described as a risk factor for impossible mask ventilation. Neck radiation has been implicated as a causative factor in postextubation airway obstruction due to airway edema.<sup>24</sup> The concomitant limitations in

neck mobility may be associated with difficult intubation.<sup>16,25</sup> In addition, an emergent surgical airway may be more difficult in patients with a history of neck radiation. Although many patients with a history of neck radiation are often electively directed to awake fiberoptic intubation by providers, our dataset included 310 patients with neck radiation. Of note, all but three patients could be ventilated. However, both univariate and multivariate analyses demonstrated neck radiation to be the most predictive factor in impossible mask ventilation (tables 1 and 4). Clearly, neck radiation results in a wide spectrum of pathophysiology. Using an observational dataset, we struggle to comment on specific features that may result in impossible mask ventilation among the many patients that have a history of neck radiation. Nevertheless, the data demonstrate that neck radiation changes should pique the clinician's concern for not only difficult intubation, but also impossible mask ventilation. The possible challenges with the ultimate rescue airway technique—a surgical airway—make neck radiation evaluation an important element of any airway assessment.

Overall, our prediction model offers excellent discriminating capability, with a c-statistic of  $0.80 \pm 0.03$  for the full model fit. When simplified for clinical usability by assigning one point for each risk factor, the unweighted risk scale demonstrates a c-statistic of  $0.75 \pm 0.03$ , consistent with current difficult mask ventilation prediction systems.<sup>3,5</sup> Providers may wish to consider patients with three or more risk factors to be at markedly increased risk for impossible mask ventilation, given an odds ratio of 8.9 when compared to patients with no risk factors. Despite the encouraging c-statistic of the unweighted risk scale, the ability to predict impossible mask ventilation effectively is limited because of its extremely low incidence.<sup>26</sup> Unfortunately, providers may often encounter patients with three or more features associated with impossible mask ventilation; given the low overall incidence of impossible mask ventilation, we cannot espouse the routine use of conservative measures such as awake fiberoptic intubation for all of these patients. However, special consideration must be given to the patient who presents with neck radiation changes and additional impossible mask ventilation risk factors.

Our data are affected by several important limitations. First, as an observational study, we could not enforce a specific care protocol or airway management algorithm. As a result, we cannot ensure that optimal or even similar mask ventilation techniques were used by every provider involved. Although the definition of impossible mask ventilation used at our institution requires multiple attempts using multiple adjuvants and providers, we cannot ensure that all providers persevered for a similar duration. In addition, more objective measures such as prolonged

pulse oximetry hypoxemia, low observed tidal volumes, or high peak airway pressures were not used. Second, the data were collected as part of the clinical care delivered. As a result, the data reflect the electronic medical record, and no additional data elements are available. For example, the clinical concept of neck radiation changes encompasses a wide range of physical presentations. Nevertheless, our dataset equates all these patients if the provider chose neck radiation changes from the pick list for the neck anatomy data element. Although there were no rigorous processes to validate the entry of data, all the independent variables have excellent data entry rates (table 1). Although selections were standardized as part of the clinical information system (appendix 1), users were not specifically trained on the definitions of the clinical terms. We are also unable to provide conclusions on the role of muscle relaxants in causing or improving mask ventilation challenges because the documentation for each case did not include a mask ventilation assessment before and after administration of neuromuscular blockade.

Moreover, the data are from a single tertiary care center that may not serve as a representative sample of patients throughout the world. From a statistical analysis perspective, our model is likely “over-fit” given the small number of events ( $n = 77$ ) in comparison to the studied independent variables ( $n = 18$ ).<sup>14</sup> This challenge is difficult to avoid given the low incidence of the studied outcome. Finally, the study of the difficult airway will always be challenged by the ethical responsibility to divert concerning patients to conservative airway management techniques that preclude an attempt at mask ventilation. Although we have previously shown that our patient population includes many high-risk patients,<sup>3</sup> the very highest-risk patients probably underwent an awake fiberoptic intubation. This may alter the validity of our statistical analyses because the most aberrant patient characteristics (*e.g.*, supermorbid obesity, severely limited thyromental distance, *etc.*) may not be available for comparison against patients who are easy to mask ventilate.

Despite these limitations, our data offer valuable insight into a concerning clinical event that is difficult to study. The study of impossible mask ventilation requires a large observational dataset due to its low incidence.<sup>27</sup> Our data demonstrate that although many impossible mask ventilation patients may be difficult to intubate, most can be managed without a surgical airway. In addition, we have derived a risk prediction scale for impossible mask ventilation with an encouraging discriminating capability. Finally, we have identified neck radiation as an important predictor of impossible mask ventilation.

## Appendix 1. Airway Physical Exam and History Elements

Element	Pick-list Choices
Cervical spine	Limited extension, limited flexion, known unstable, possible unstable
Neck anatomy	Limited laryngeal mobility, mass, radiation changes, thick/obese, thyroid cartilage not visible, tracheal deviation
Thyroid cartilage to mentum distance	< 6 cm or ≥ 6 cm
Mouth opening interincisor or intergingival distance	< 3 cm or ≥ 3 cm
Mandibular protrusion test	Normal, lower incisors can be protruded anterior to upper incisors; limited, lower incisors can be advanced to only meet upper incisors; severely limited, lower incisors cannot be advanced to meet upper incisors
Mallampati classification	I, II, III, or IV as modified by Samssoon and Young <sup>8</sup> ; performed with patient sitting with head in neutral flexion/extension position, tongue out, without phonation
Full beard	Yes, no, moustache, or goatee
Dentition	Normal, dentures upper partial, dentures upper complete, dentures lower partial, dentures lower complete, edentulous, teeth missing/loose/broken
Snoring	History of snoring occurring nightly
Obstructive sleep apnea	History of obstructive sleep apnea requiring continuous positive airway pressure, bilevel positive airway pressure, or surgery

## References

- Practice guidelines for management of the difficult airway: An updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *ANESTHESIOLOGY* 2003; 98:1269-77
- Yentis SM: Predicting trouble in airway management. *ANESTHESIOLOGY* 2006; 105:871-2
- Kheterpal S, Han R, Tremper KK, Shanks A, Tait AR, O'Reilly M, Ludwig TA: Incidence and predictors of difficult and impossible mask ventilation. *ANESTHESIOLOGY* 2006; 105:885-91
- Calder I, Yentis SM: Could 'safe practice' be compromising safe practice? Should anaesthetists have to demonstrate that face mask ventilation is possible before giving a neuromuscular blocker? *Anaesthesia* 2008; 63:113-5
- Langeron O, Masso E, Huriaux C, Guggiari M, Bianchi A, Coriat P, Riou B: Prediction of difficult mask ventilation. *ANESTHESIOLOGY* 2000; 92:1229-36
- Yildiz TS, Solak M, Tokar K: The incidence and risk factors of difficult mask ventilation. *J Anesth* 2005; 19:7-11
- Han R, Tremper KK, Kheterpal S, O'Reilly M: Grading scale for mask ventilation (letter). *ANESTHESIOLOGY* 2004; 101:267
- Samssoon GL, Young JR: Difficult tracheal intubation: A retrospective study. *Anaesthesia* 1987; 42:487-90
- Bennett JA, Abrams JT, Van Riper, DF, Horrow JC: Difficult or impossible ventilation after sufentanil-induced anesthesia is caused primarily by vocal cord closure. *ANESTHESIOLOGY* 1997; 87:1070-4
- Gentili ME: Is difficult mask ventilation only correlated to the physical status of the patient? (letter). *ANESTHESIOLOGY* 2001; 94:935
- Cormack RS, Lehane J: Difficult tracheal intubation in obstetrics. *Anaesthesia* 1984; 39:1105-11
- Barash PG, Cullen BF, Stoelting RK: *Clinical Anesthesia*, 5th Edition. Philadelphia, Lippincott Williams & Wilkins, 2006; pp 334-52
- Rassi A Jr, Rassi A, Little WC, Xavier SS, Rassi SG, Rassi AG, Rassi GG, Hasslocher-Moreno A, Sousa AS, Scanavacca MI: Development and validation of a risk score for predicting death in Chagas' heart disease. *N Engl J Med* 2006; 355:799-808
- Harrell FE Jr, Lee KL, Matchar DB, Reichert TA: Regression models for prognostic prediction: Advantages, problems, and suggested solutions. *Cancer Treat Rep* 1985; 69:1071-7
- Adnet F: Difficult mask ventilation: an underestimated aspect of the problem of the difficult airway? *ANESTHESIOLOGY* 2000; 92:1217-8
- el-Ganzouri AR, McCarthy RJ, Tuman KJ, Tanck EN, Ivankovich AD: Pre-operative airway assessment: Predictive value of a multivariate risk index. *Anesth Analg* 1996; 82:1197-204
- Benyamin RM, Wafai Y, Salem MR, Joseph NJ: Two-handed mask ventilation of the difficult airway by a single individual (letter). *ANESTHESIOLOGY* 1998; 88:1134
- Chou HC, Wu TL: Large hypopharyngeal tongue: A shared anatomic abnormality for difficult mask ventilation, difficult intubation, and obstructive sleep apnea? *ANESTHESIOLOGY* 2001; 94:936-7
- Conlon NP, Sullivan RP, Herbison PG, Zacharias M, Buggy DJ: The effect of leaving dentures in place on bag-mask ventilation at induction of general anesthesia. *Anesth Analg* 2007; 105:370-3
- Durga VK, Millns JP, Smith JE: Manoeuvres used to clear the airway during fiberoptic intubation. *Br J Anaesth* 2001; 87:207-11
- Garewal DS, Johnson JO: Difficult mask ventilation. *ANESTHESIOLOGY* 2000; 92:1199-200
- Liang Y, Kimball WR, Kacmarek RM, Zapol WM, Jiang Y: Nasal ventilation is more effective than combined oral-nasal ventilation during induction of general anesthesia in adult subjects. *ANESTHESIOLOGY* 2008; 108:998-1003
- Takenaka I, Aoyama K, Kadota T: Mandibular protrusion test for prediction of difficult mask ventilation (letter). *ANESTHESIOLOGY* 2001; 94:935
- Burkle CM, Walsh MT, Pryor SG, Kasperbauer JL: Severe postextubation laryngeal obstruction: The role of prior neck dissection and radiation. *Anesth Analg* 2006; 102:322-5
- Shiga T, Wajima Z, Inoue T, Sakamoto A: Predicting difficult intubation in apparently normal patients: A meta-analysis of bedside screening test performance. *ANESTHESIOLOGY* 2005; 103:429-37
- Yentis SM: Predicting difficult intubation-Worthwhile exercise or pointless ritual? *Anaesthesia* 2002; 57:105-9
- Avorn J: In defense of pharmacoepidemiology-embracing the yin and yang of drug research. *N Engl J Med* 2007; 357:2219-21