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Predicting Trouble in Airway Management

FOR an anesthetist, there can be few, if any, more alarming clinical situations than the unexpected total inability to manage a patient's airway. That this occurs rarely is of course a good thing, although its rarity itself both encourages complacency and makes it difficult to study.

The first problem is defining the problem. Historically, anesthetists have focused on tracheal intubation, perhaps because it has traditionally been an exclusive anesthetic skill and is seen as the definitive airway technique, and because difficult or failed intubation has been such an important cause of anesthetic morbidity and mortality over the years. However, difficult intubation is not easy to define, because there are degrees of difficulty and they may vary between intubators. Defining *failed* intubation might seem, on the face of it, easier, but there are different thresholds for declaring failure, depending on the would-be intubator, the urgency of the situation, and who or what else is available, and a second person (or even a third) may succeed when the first has failed. These difficulties, plus the rarity of failure, have led to use of the view obtained at direct laryngoscopy—albeit using different methods of grading the view—as a surrogate for difficult or failed intubation in clinical studies (reviewed recently by Shiga *et al.*[1]). These studies generally find the same thing: that certain clinical features are more likely to be present in patients in whom laryngoscopy is difficult, but because most laryngoscopies are easy, most patients who have such features actually pose no problems.

But even if it were possible to predict difficult laryngoscopy accurately, this is not quite what we need to know. First, an endotracheal tube may be easy to place despite a poor laryngoscopic view, and even a reasonable view may be associated with difficulty passing a tube. Second, failed intubation alone may not necessarily lead to disaster, because there are alternative ways of maintaining oxygenation, the most simple of which is ventilation by facemask.

Surprisingly, predicting difficult mask ventilation has attracted little attention—perhaps, again, at least partly because of its rarity and difficulty in defining it. In this issue of the Journal, Kheterpal *et al.*[2] have added to the work of Langeron *et al.*[3] in this area, both groups finding that obesity, older age, snoring, and the presence of a beard stood out as risk factors for difficulty (both groups suggesting that beards that stood out too much should perhaps be removed, although they do not suggest remedial action for obesity). As with tracheal intubation, though, most people, including those with these risk factors—difficulty defining snoring or beards notwithstanding—are easy to ventilate by mask. And, as with intubation, predicting difficult mask ventilation does not give us what we really need to know: More useful would be the ability to predict which patients are at risk from difficulty with both intubation and mask ventilation, because if there is trouble with one technique, the anesthetist can simply use the other in most cases. Kheterpal *et al.* looked at this too, and although numbers were small, they identified obesity, snoring, limited jaw movement, and abnormal neck anatomy as risk factors.

But is this what we really need to know either? With the laryngeal mask airway now such a valued component of airway management strategies[4,5] and so widely and readily available, perhaps we should strive to predict in which patients there will be difficulty with intubation, mask ventilation, *and* ventilation with the laryngeal mask airway? Kheterpal *et al.* found only 37 patients out of 22,660 in whom mask ventilation was impossible; intubation was difficult in 10 of these, and surgical cricothyrotomy was required in 1. Details of other methods of airway management that were attempted in this single case are not provided, but it is difficult to imagine cricothyrotomy being performed without trying the laryngeal mask airway or equivalent first. A definitive study of this aspect would be challenging, mainly because the number of patients unfortunate enough to fulfill these criteria is tiny.

All of this brings us to the next problem, at which I have been hinting above—*i.e.*, the limited usefulness of predictive tests when the thing they are trying to predict is very rare. In such a situation, unless there is near 100% sensitivity and specificity, the positive and negative predictive values will be low. In the case of airway management, most patients are easy to manage and most patients predicted to be difficult are not, whereas a few who are predicted to be easy are anything but. Understanding this limitation is important if the so-called predictive tests are to be used sensibly.[6]

Finally, a weakness of most prediction studies is that their findings only relate to the sample from which they were derived. Kheterpal *et al.* should be commended for gathering data from more than 22,000 patients; their findings must now be validated in another sample, and one can only hope that the same group, or another one, is ready to take up the challenge, if not the beard trimmers.

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Pressure-support Ventilation in the Operating Room

Do We Need It?

ADVANCES in technology have contributed to our ability to better care for critically ill patients. New methods of ventilatory support (such as pressure-support, pressure-controlled inverse ratio, and airway pressure-release ventilation) in the intensive care unit (ICU) have allowed for easier weaning and a decrease in barotrauma.[1] The study by Jaber *et al.*[2] compares the pressure-support ventilatory (PSV) mode in ICU ventilators with the recently introduced pressure support in ventilators used in operating room (OR) anesthesia workstations.

The initial method of mechanical ventilation in the OR was pressure-controlled ventilation. In this mode, the ventilator is set to deliver a certain pressure to the airway and maintain that pressure through the period of inspiration. As gas flows through the pressurized system to the patient's lungs, a tidal volume is generated (inspiration). The duration of inspiration depends on the respiratory rate and the inspiratory-to-expiratory ratio set by the operator. In some other ventilators, the inspiratory-to-expiratory ratio is set by increasing or decreasing the gas flow rate (increasing the flow rate during inspiration shortens the inspiratory time and prolongs exhalation, whereas decreasing the flow rate results in the opposite).

The tidal volume delivered to the patient by this mode is dependent on the lung compliance and the airway resistance. In stiff lungs (pulmonary edema, interstitial fibrosis, and adult respiratory distress syndrome), the compliance of the lung is low (unable to expand), and this results in a smaller tidal volume for the given preset pressure. In cases of bronchial asthma, mucus plugging, or kinking of the endotracheal tube, the preset pressure is reached quickly, and the delivered tidal volume is also low.

The pressure-support mode of ventilation is derived from the pressure-controlled mode. In the pressure-support mode of ventilation, the ventilator senses the patient's initiation of a breath by either a decrease in the flow rate or a decrease in the circuit pressure. When this reaches a preset threshold, usually -2 cm H_2O, the ventilator is triggered and delivers a preset pressure (5–15 cm H_2O) to augment the patient's tidal volume. In the latter part of inspiration, the flow rate starts to decrease. When the inspiratory flow rate reaches another preset value, (usually a decline of approximately 25%), the ventilator ceases to deliver the preset pressure. This then allows the patient to exhale. The tidal volumes vary, as in the pressure-control mode.

In this well-designed study, the authors test the performance of the ventilators in five anesthesia work stations against the performance of four traditional ICU ventilators. The results showed that three of the five anesthesia ventilators performed close to the ICU ventilators in time delay and pressurization at different levels of pressure support. Spontaneous ventilation in critically ill patients with multiple medical problems can be quite advantageous. Therefore, the ability to ventilate these patients in the OR with the same level of ventilatory support they were receiving in the ICU may prove to be the least disruptive to their oxygenation and ventilation status, which is already compromised.

This study was performed in a laboratory setting under controlled conditions. Studies need to be performed in the clinical setting to evaluate the actual advantages and disadvantages of the PSV mode in anesthetized patients. In their study, Jaber *et al.* found that two of the five anesthesia ventilators that they tested did not perform up to the ICU ventilator standards. We do not know whether these differences are clinically significant. However, if they are clinically important, it would be incumbent on the anesthesiologist to ensure that new OR

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ventilators were functionally equivalent to their ICU counterpart before purchasing new machines.

However, we suspect that only a small number of ICU patients would actually benefit from the PSV mode in the OR. Most ICU patients who are on PSV are in the process of being weaned from mechanical ventilation. These patients are particularly vulnerable to respiratory depressant drugs. When they come to the OR, they require inhalation anesthesia and/or narcotics that cause respiratory depression. The previous settings for PSV that maintained adequate ventilation may no longer be adequate to prevent hypoxia or hypercapnia. This results in the need to increase ventilatory support. Also, the surgical procedure may require the patient to be in certain positions, (*i.e.*, lateral, prone, or steep Trendelenburg), which may not be well tolerated by an already compromised patient who is breathing spontaneously. Finally, if the surgical procedure required muscle relaxants, it would be impossible to continue using the PSV mode.

The PSV mode may be used in the OR in spontaneously breathing patients who are undergoing peripheral surgery with a laryngeal mask airway or an endotracheal tube. Potential advantages of this are an increase in tidal volume and a decrease in the work of breathing. Many of these patients are healthy and have a large respiratory reserve. When using the PSV mode in these patients, some prolongation in delay time, triggering, or pressurization probably will not have an adverse effect.

However, Jaber *et al.* did not study the ventilators in PSV mode with changes in resistance or compliance; therefore, it is not possible to know what effects, if any, this would have on ventilation. There are also issues of patient safety. Devitt *et al.*[3] showed that in patients ventilated with a laryngeal mask airway, as the inflation pressure increased, so did the leak around the laryngeal mask airway, as well as the amount of gas entering the stomach. Currently, it is unknown how a leak around the laryngeal mask airway (using the PSV mode) would affect the tidal volume delivered or the anesthesiologist's ability to detect a decrease in minute ventilation.

Continuing advances in ventilator technology could greatly affect the outcome of critically ill patients. By including these new modes of ventilation into anesthesia workstations, anesthesiologists may be able to minimize adverse effects that can occur when a critically ill patient comes to the OR. We see this study as an important addition to the literature because it shows that technology improvements in traditional intensive care ventilators can be transferred to the OR. Unlike the early OR ventilators, which were merely pressure generators or time cycled-flow generators with a preset maximum pressure limit, the modern OR ventilators are microprocessor-driven, sophisticated machines. However, as with any new technology, the anesthesiologist must understand its indications and limitations, know how to properly implement it, and determine its cost effectiveness.

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If You Prick Us, Do We Not Bleed?

IN Shylock's soliloquy in *The Merchant of Venice*,[1] in his appeal for lack of bias, Shakespeare invoked a physiologic event (the title of this editorial) that would have been known as well to the 17th-century audience as it is to 21st-century anesthesiologists. Although that Elizabethan trespass was surely less severe than is modern spinal reconstruction, total hip arthroplasty, or sternotomy and cardiopulmonary bypass, the qualitative result is the same: hemorrhage. Countless studies have examined hemorrhage, including many evaluating a substantial variety of therapeutic and pharmacologic maneuvers aimed at reducing hemorrhage and the ensuing complications when hemorrhage is not treated adequately. Despite the many pleas for the elimination of bias, as was Shylock's, those requests have not been heeded fully. His own plea presaged his being thwarted in obtaining a pound of flesh, because he could not perform the surgery without blood loss[2] any more than it can be accomplished today.

In this issue of ANESTHESIOLOGY, Zufferey *et al.*[3] examine a modern therapy aimed at decreasing hemorrhage in-

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Incidence and Predictors of Difficult and Impossible Mask Ventilation

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Background: **Mask ventilation is an essential element of airway management that has rarely been studied as the primary outcome. The authors sought to determine the incidence and predictors of difficult and impossible mask ventilation.**

Methods: **A four-point scale to grade difficulty in performing mask ventilation (MV) is used at the authors' institution. They used a prospective, observational study to identify cases of grade 3 MV (inadequate, unstable, or requiring two providers), grade 4 MV (impossible to ventilate), and difficult intubation. Univariate and multivariate analyses of a variety of patient history and physical examination characteristics were used to establish risk factors for grade 3 and 4 MV.**

Results: **During a 24-month period, 22,660 attempts at MV were recorded. 313 cases (1.4%) of grade 3 MV, 37 cases (0.16%) of grade 4 MV, and 84 cases (0.37%) of grade 3 or 4 MV and difficult intubation were observed. Body mass index of 30 kg/m^2 or greater, a beard, Mallampati classification III or IV, age of 57 yr or older, severely limited jaw protrusion, and snoring were identified as independent predictors for grade 3 MV. Snoring and thyromental distance of less than 6 cm were independent predictors for grade 4 MV. Limited or severely limited mandibular protrusion, abnormal neck anatomy, sleep apnea, snoring, and body mass index of 30 kg/m^2 or greater were independent predictors of grade 3 or 4 MV and difficult intubation.**

Conclusions: **The authors observed the incidence of grade 3 MV to be 1.4%, similar to studies with the same definition of difficult MV. Presence of a beard is the only easily modifiable independent risk factor for difficult MV. The mandibular protrusion test may be an essential element of the airway examination.**

MASK ventilation (MV) is an essential component of airway management and the delivery of general anesthesia.[1] Successful MV provides anesthesia practitioners with a rescue technique during unsuccessful attempts at laryngoscopy and unanticipated difficult airway situations. Although there is an extensive body of literature addressing predictive factors for difficult laryngoscopy and grading its view, investigations that focus on MV are limited.[2,3]

In 2000, Langeron *et al.*[4] characterized predictive factors for and incidence of difficult mask ventilation (DMV). In an accompanying editorial, Adnet[3] recommended establishing a MV numerical scale. In 2004, Han *et al.*[5] described a grading scale for MV consisting of four categories (grades 1–4), with grade 3 and 4 describing specific criteria for DMV and impossible mask ventilation (IMV), respectively.

Given the limited data regarding DMV and almost complete absence of data regarding IMV, the objectives of the current study included a confirmation of Langeron's predictive factors for DMV, evaluation of associations between previously unstudied parameters and DMV, determination of the incidence of both DMV and IMV, and evaluation of final airway outcome in cases of IMV.

Materials and Methods

After obtaining institutional review board approval (University of Michigan, Ann Arbor, Michigan), all adult patients undergoing general anesthesia were prospectively included in this trial. Because no clinical interventions were studied and no patient-identifiable data were used, signed patient informed consent was waived per the institutional review board approval. For each anesthetic case, a preoperative history and physical and intraoperative record were documented using an electronic perioperative clinical information system (Centricity®; General Electric Healthcare, Waukesha, WI). Elements documented included a standard airway physical examination, physical features that may affect mask fit, patient history that may suggest airway anatomy pathology, and general patient and operation characteristics (tables 1 and 2).[6,7]

The primary outcome measure was ease or difficulty of MV. A four-point scale ranging from grade 1 to 4 originally described by Han *et al.*[5] is used at our facility (table 3). Grade 3 (DMV) is defined as MV that is inadequate to maintain oxygenation, unstable MV, or MV requiring two providers. Grade 4 MV is defined as IMV noted by absence of end-tidal carbon dioxide measurement and lack of perceptible chest wall movement during positive-pressure ventilation attempts despite airway adjuvants and additional personnel. Two incidence pilot studies were previously performed by Han *et al.*.[5] Previous studies suggest that the use of muscle relaxant does not alter the grade MV assigned.[4,8] Secondary outcomes mea-

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Table 1. Airway Physical Examination and History Elements

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, ≥ 6 cm)
Mouth opening interincisor or intergingival distance (< 3 cm, ≥ 3 cm)
Mandibular protrusion test[6] (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 Samsoon and Young,[7] 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)
History of cough (chronic, recent, productive, nonproductive)
History of rhinorrhea
History of chronic obstructive pulmonary disease (chronic bronchitis or emphysema requiring treatment with inhaled or systemic steroids or bronchodilators)
History of asthma (requiring treatment with inhaled or systemic steroids or bronchodilators)
History of snoring occurring nightly
History of obstructive sleep apnea requiring continuous positive airway pressure, bilevel positive airway pressure, or surgery

sured were direct laryngoscopy (DL) view as defined by Cormack and Lehane,[9] a subjective assessment of difficult intubation (DI) due to more than three attempts by anesthesia attending staff, and the ability to perform successful tracheal intubation using DL. These data were collected using standardized pick-list choices with the option of free text entry if the choices did not offer the anesthesiologist the ability to fully document the clinical observation.

Anesthesia services were provided by anesthesiology attending staff with assistance from certified registered nurse anesthetists, anesthesia residents, and fellows in training. In general, both MV and intubation were attempted initially by the anesthesiology resident or certified registered nurse anesthetists present in the room. All clinical decisions regarding airway management (patient position, DL blade, use of thyroid pressure) were made by the attending staff. The attending could choose to perform an awake fiberoptic intubation at their discretion, thereby avoiding a MV attempt. MV was performed without a harness 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 DL handle and blade (Heine Inc., Dover, NH). DI was defined as grade III or IV DL view or more than three attempts at intubation by a staff anesthesiologist. Impossible intubation was defined as the inability to intubate the patient using DL technique despite more than three attempts.

Table 2. General Patient and Operation Characteristics

Body mass index [weight in kilograms/(height in meters)^2]
Patient age in years at time of procedure
American Society of Anesthesiologists physical status (I–VI, E denoting emergency)
Emergent surgical procedure (yes/no)
Operation planned
Operative surgical service
Experience level of anesthetist (intern, clinical anesthesia-1, clinical anesthesia-2, clinical anesthesia-3, fellow, or certified registered nurse anesthetist)

Table 3. Mask Ventilation Scale and Incidence

Grade	Description	n (%)
1	Ventilated by mask	17,535 (77.4)
2	Ventilated by mask with oral airway/adjuvant with or without muscle relaxant	4,775 (21.1)
3	Difficult ventilation (inadequate, unstable, or requiring two providers) with or without muscle relaxant	313 (1.4)
4	Unable to mask ventilate with or without muscle relaxant	37 (0.16)
	Total cases	22,260

Based on the work by Langeron *et al.*[4] and Han *et al.*[5], we estimated that we would need to observe approximately 20,000 cases of MV to record 1,000 cases of difficult ventilation and 20 cases of impossible ventilation. We initially set our sample size and study duration to attain these sample sizes.

Statistical Analysis

Univariate analysis was performed between patients with or without the following measured outcomes: grade 3 MV, grade 4 MV, and grade 3 or 4 MV and DI. Statistical significance was tested using Pearson chi-square or Fisher exact test. A *P* value less than 0.05 was considered significant. All variables found to be significant in the univariate analysis were entered into a multivariate logistic regression model to identify independent predictors of the measured outcome.

If three or more risk factors were identified for an outcome, a risk factor scale was created to predict the outcome. Receiver operating characteristic curves and odds ratios were analyzed to assess the diagnostic value of the risk factor scale.

Results

Of 61,252 anesthetic cases performed in adult patients during a 24-month period, 22,660 cases included an attempt at MV. Thirty-seven cases (0.16%) of grade 4 MV (impossible to ventilate) and 313 cases (1.4%) of grade 3 MV (difficult to ventilate) were recorded (table 3). Two cases of IMV were due to an existing patent tracheotomy site and were excluded from these data. No other patient exclusions were performed. Eighty-four cases (0.37%) of grade 3 or 4 MV and DI were observed.

During the first 9 months of the study period, the mandibular protrusion test was not recorded in the preoperative anesthesia history and physical form. Therefore, only 14,369 cases were included in the univariate and multivariate predictor analysis. All episodes of grade 3 or 4 MV were included in the analysis.

Univariate analysis demonstrated several risk factors associated with grade 3 MV, grade 4 MV, and grade 3 or 4 MV with DI (table 4). Body mass index (BMI) of 30 kg/m^2 or greater and age of 57 yr or older maximized the sum of sensitivity and specificity for each risk factor. Multivariate regression analysis identified the following independent predictors of grade 3 MV: BMI of 30 kg/m^2 or greater, presence of a beard, Mallampati classification III or IV, age of 57 yr or older, severely limited mandibular protrusion, and a history of snoring (table 5). These six indicators were used to create a prediction score. A patient was given one point if a preoperative predictor was noted. The area under the curve for the receiver operating characteristic curve was 0.75 (fig. 1). Weighting the factors did not improve the curve.

Multivariate regression identified history of snoring ($P = 0.004$) and thyromental distance of less than 6 cm ($P = 0.040$) as independent predictors of grade 4 MV.

Multivariate regression analysis identified the following independent predictors of grade 3 or 4 MV combined with DI: limited or severely limited mandibular protrusion, thick/obese neck anatomy, history of sleep apnea, history of snoring, and BMI of 30 kg/m^2 or greater (table 5). The receiver operating characteristic curve demonstrated an area under the curve of 0.78 (fig. 2).

Of the 37 cases of grade 4 MV, only 1 patient could not be intubated and required emergent cricothyrotomy. Ten patients had a DI, and 26 were intubated without difficulty.

Table 4. Univariate Predictors of Airway Outcomes

	Grade 3 Mask Ventilation			Grade 4 Mask Ventilation			Grade 3 or 4 Mask Ventilation and Difficult Intubation		
	No (n = 14,057)*	Yes (n = 313)*	*P* Value	No (n = 14,332)*	Yes (n = 37)*	*P* Value	No (n = 14,285)*	Yes (n = 84)*	*P* Value
Mallampati III or IV	1,188 (8.6)	70 (23)	< 0.001	1,252 (8.9)	6 (17)	NS	1,221 (8.7)	37 (45.7)	< 0.001
Abnormal cervical spine†	1,108 (8)	37 (14)	0.001	1,139 (8.1)	6 (20)	0.013	1,160 (8.1)	15 (20.3)	< 0.001
Thick/obese neck anatomy	1,397 (10)	95 (34)	< 0.001	1,477 (11)	15 (48)	< 0.001	1,455 (11)	37 (49)	< 0.001
Abnormal neck anatomy‡	153 (1.2)	4 (2.2)	NS	154 (1.2)	3 (16)	0.002	155 (1.2)	2 (4.9)	NS
Edentulous dentition	522 (4.4)	25 (15)	< 0.001	544 (4.5)	3 (13)	NS	545 (4.5)	2 (4.3)	NS
Thyromental distance < 6 cm	901 (6.5)	30 (11)	0.007	926 (6.6)	5 (16)	0.039	913 (6.5)	18 (23.4)	< 0.001
Mouth opening < 3 cm	553 (4)	20 (6.8)	0.016	571 (4.1)	2 (6.3)	NS	564 (4)	9 (11.5)	0.001
Limited MPT	1,333 (9.8)	24 (15)	0.042	1,355 (9.8)	2 (9.1)	NS	1,348 (9.8)	9 (22.5)	< 0.001
Beard	1,371 (9.9)	62 (20)	< 0.001	1,427 (10)	6 (17)	NS	1,421 (10)	12 (15)	NS
Cough	380 (2.7)	20 (6.5)	< 0.001	399 (2.8)	1 (2.7)	NS	397 (2.8)	3 (3.6)	NS
Rhinorrhea	65 (0.5)	2 (0.6)	NS	67 (0.5)	0 (0)	NS	67 (0.5)	0 (0)	NS
COPD	792 (5.7)	28 (9.1)	0.011	818 (5.8)	2 (5.4)	NS	816 (5.8)	4 (4.8)	NS
Asthma	1,133 (8.2)	27 (8.9)	NS	1,158 (8.2)	2 (5.9)	NS	1,149 (8.2)	11 (14)	NS
Snoring	3,505 (27)	83 (50)	< 0.001	3,576 (27)	12 (57)	0.002	3,560 (27)	28 (67)	< 0.001
Sleep apnea	651 (4.7)	49 (16)	< 0.001	693 (4.9)	7 (19)	< 0.001	682 (4.8)	18 (22)	< 0.001
Body mass index ≥ 25 kg/m^2	8,843 (64)	270 (90)	< 0.001	9,083 (64)	30 (81)	0.033	9,039 (64)	74 (91)	< 0.001
Age ≥ 55 yr	5,952 (42)	171 (55)	< 0.001	6,107 (43)	16 (43)	NS	6,090 (43)	43 (51)	NS
Emergent operation	384 (2.7)	15 (4.3)	NS	397 (2.8)	2 (5.6)	NS	593 (2.8)	6 (7.1)	0.015
Resident anesthetist§	8,581 (62)	266 (85)	< 0.001	8,823 (62)	24 (65)	NS	8,785 (62)	62 (74)	0.029

Data are n (%).

* Cases with missing data for the specific predictor are excluded from percentage calculation. † Defined as limited extension, limited flexion, known unstable, possible unstable. ‡ Defined as limited laryngeal mobility, radiation changes, thyroid cartilage not visible, tracheal deviation. § A comparison of the anesthesia resident patient population group with the certified registered nurse anesthetist/fellow patient population group demonstrated a highly statistically significant difference in risk factors for difficult mask ventilation. Given this difference in acuity, anesthetic performed by resident was removed from the multivariate regression analysis despite being significant in the univariate analysis.

COPD = chronic obstructive pulmonary disease; MPT = mandibular protrusion test; NS = not significant.

Table 5. Airway Outcome Independent Predictors

Factor	*P* Value
Grade 3 mask ventilation	
Body mass index ≥ 30 kg/m²	< 0.0001
Beard	< 0.0001
Mallampati III or IV	< 0.0001
Age ≥ 57 yr	0.002
Jaw protrusion—severely limited	0.018
Snoring	0.019
Grade 3 or 4 mask ventilation and difficult intubation	
Jaw protrusion—limited or severely limited	< 0.0001
Thick/obese neck anatomy	0.019
Sleep apnea	0.036
Snoring	0.049
Body mass index ≥ 30 kg/m²	0.053

Discussion

The results of this study confirm the incidence of grade 3 MV (1.4%) to be similar to the 1.6% incidence reported in the review of Han *et al.*[5] of 1,405 patients using the same MV scale. This is less than the 5% DMV incidence reported in the study of Langeron *et al.*[4] using a different MV scale. Grade 4 MV (IMV) has an incidence of 0.16% in the studied tertiary care center surgical patient population. Abnormalities in the mandibular protrusion test may be associated with grade 3 MV. Although grade 4 MV is associated with DI, an overwhelming majority of patients can still be intubated.

Langeron *et al.*[4] reported the incidence and predictors of DMV in a study of 1,502 adult patients designed explicitly for this endpoint. The 1.4% observed incidence of grade 3 MV in our population was markedly lower than that reported by Langeron *et al.*[4] (5%) but similar to that reported by Han *et al.*[5] (1.5%), Asai *et al.*[10] (1.4%), and Rose and Cohen[11] (0.9%). This is most likely due to the different definitions of DMV. Historically, only three categories of MV have been used (easy, difficult, and impossible).[1,4,12] Of note, our inclusion of a grade 2 definition (ventilated by mask with oral airway/adjuvant with or without muscle relaxant) is applicable to attempts that are neither easy nor difficult. This may be the most important explanation for why our incidence of grade 3 MV was lower than Langeron's incidence of DMV. Our study participants were able to describe an airway that was not "easy" but nevertheless presented some challenges. Clinically, neither grade 1 nor grade 2 MV raises significant clinical concern for the experienced anesthetist. This is similar to the four-point scales used to describe DL view (Cormack and Lehane) and oropharyngeal anatomy (Mallampati examination as modified by Samsoon and Young).[7,9] The American Society of Anesthesiologists Task Force on Management of the Difficult Airway succinctly defined DI as intubation requiring "multiple attempts,"[1] whereas the definition of DMV was a list of signs and symptoms ranging from objective monitoring abnormalities to subjective assessments of adequacy of air movement.[1] Although Han's MV scale is also limited by definitions including multiple signs and symptoms, the four-point scale may be superior at discriminating clinically significant MV challenges. Although other small studies have identified similar DMV rates, Langeron's three categories and 5% DMV inci-

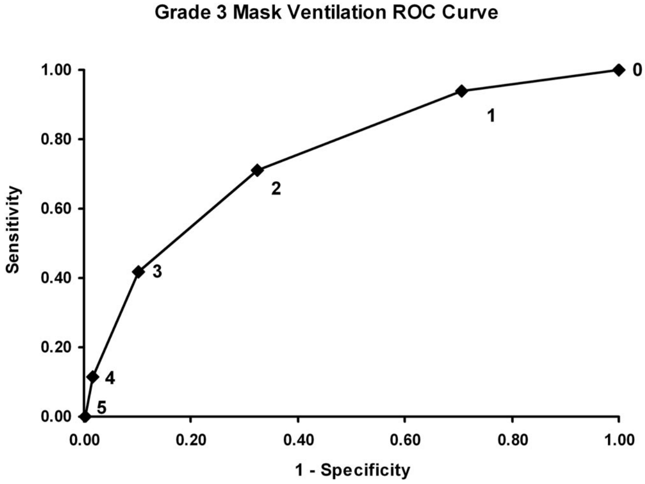

Fig. 1. A receiver operating characteristic (ROC) curve evaluating the sensitivity and specificity of risk factors for grade 3 (difficult) mask ventilation. Six independent predictors for difficult mask ventilation were observed: body mass index of 30 kg/m² or greater, presence of a beard, Mallampati classification III or IV, age of 57 yr or older, severely limited mandibular protrusion, and a history of snoring. A prediction score for difficult mask ventilation was based on how many of these risk factors a patient possessed. The ROC curve assists practitioners in evaluating the value of a test and in establishing an appropriate cutoff for tests that posses a range of scores. The area under the curve for the difficult mask ventilation ROC curve was 0.75.

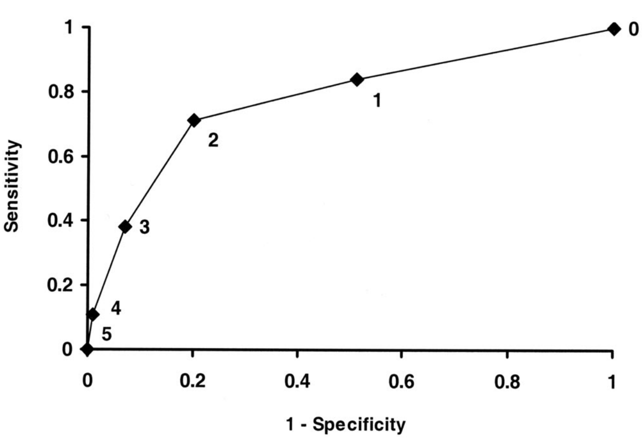

Fig. 2. A receiver operating characteristic (ROC) curve evaluating the sensitivity and specificity of risk factors for grade 3 (difficult) or 4 (impossible) mask ventilation and difficult intubation (grade III or IV direct laryngoscopy view or 4+ intubation attempts by staff). Five independent predictors were observed: limited or severely limited mandibular protrusion, thick/obese neck anatomy, a history of sleep apnea, a history of snoring, and body mass index of 30 kg/m² or greater. A prediction score for difficult mask ventilation and intubation was based on how many of these risk factors a patient possessed. The area under the curve for the difficult mask ventilation ROC curve was 0.78.

dence may overstate the incidence of clinically significant DMV.[12,13]

We were able to confirm Langeron's observation that increased BMI, presence of a beard, history of snoring, and advanced age are independent predictors of grade 3 MV. Our observations indicated an optimal sensitivity and specificity at a BMI of 30 rather than 26 kg/m² as previously reported.[4] Although significantly increased BMI has been found to be a risk factor for DI,[14] these data demonstrate that even moderately increased BMI is the most important risk factor for grade 3 MV. We have confirmed presence of a beard as an important risk factor for grade 3 MV. Poor mask fit and gas leak are the intuitive anatomical pathology relating presence of a beard and grade 3 MV.[15] A beard is the only easily modifiable risk factor for DMV. Now that it has been confirmed that a beard is a significant risk factor, we are obligated to inform patients of this risk. We may need to recommend that they shave their beard before the procedure, especially in patients with other risk factors for DMV. Further investigation in this area is necessary.

We were able to confirm that a history of snoring is associated with grade 3 MV as reported previously by Langeron *et al.*[4] and Yildiz *et al.*[12] Snoring has been shown to be related to upper airway collapse.[16] A history of obstructive sleep apnea requiring surgical or positive airway pressure treatment was not found to be related to grade 3 MV. Given the high prevalence of snoring, we had hoped to find a more specific historical or physical examination element that may provide improved positive predictive value.[17] In contrast to Langeron's findings, we were unable to identify lack of teeth as an independent predictor of grade 3 MV. Although age of 57 yr or older may seem to be the independent predictor responsible for eliminating edentulous dentition from the multivariate model, interaction analysis did not support this theory. This deviation from the results of Langeron *et al.* warrants further study.

Our data do identify a possible relation between abnormalities in the mandibular protrusion test and grade 3 MV. The jaw-thrust maneuver as a tool in restoring patency of the upper airway is a mainstay of anesthetic practice and has been described for more than 100 yr.[18] Although evaluation of the mandibular protrusion test is a part of the American Society of Anesthesiologists Task Force on Management of the Difficult Airway's standard physical examination,[1] many institutions, including ours, have not historically performed the test, been aware of its significance, or documented its findings.[19] Calder *et al.*[6] and Takenaka *et al.*[20] indicated the need to further study the value of this quick and simple test. The inability to protrude the mandible, particularly in patients with characteristics predisposing them to upper airway collapse, may be an important risk factor. Our data do indicate a role for this test as part of the standard airway

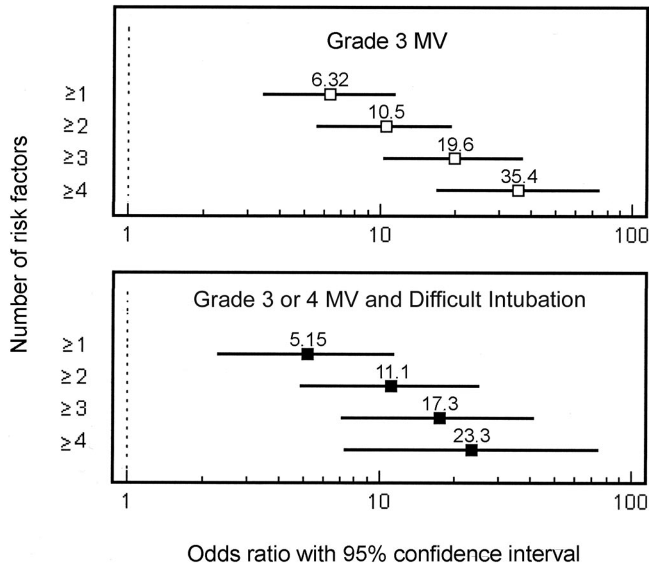

Fig. 3. The risk of grade 3 MV (*top*, *open boxes*) or grade 3/4 MV and difficult intubation (*below*, *closed boxes*) based on the number of patient risk factors. The odds ratio compares patient cohorts with a given risk level (*i.e.*, ≥ 1, ≥ 2, *etc.*) to a patient with 0 risk factors. The x-axis demonstrates the odds ratio and 95% confidence interval using a log 10 scale.

examination and its inclusion as a risk factor for grade 3 MV.

Patients with three or more points in the predictor scale had a grade 3 MV incidence of 5%, nearly 20 times the baseline incidence of 0.26% for patients with zero points (fig. 3). Some providers may wish to use a risk factor cutoff of three to guide their MV preparation. Given the morbidity associated with airway difficulty, our predictive factor system may serve to help the practitioner prepare for a possible episode of grade 3 MV by having the patient shave his beard, ensuring the presence of another anesthesia provider in the room, or preparation for alternate methods of MV.[1]

The study of IMV has been limited to anecdotal reports of its occurrence.[21,22] No previous study has been able to comment on its incidence or predictors.[13] Our series of 37 patients demonstrates the largest group of IMV patients reported thus far and may offer some insight. The incidence of grade 4 MV is rare at 0.16%, but still more frequent than other dreaded anesthesia complications such as malignant hyperthermia or homozygous atypical pseudocholinesterase.[23,24] Given that MV is an important rescue technique in cases of DI, the inability to mask ventilate represents an event with significant potential morbidity and mortality.[13] We were only able to identify two predictors of grade 4 MV: a history of snoring and thyromental distance of less than 6 cm. This is almost certainly due to limited statistical power given the relatively small number of cases available for study, masking true relations. However, it may actually reveal an underlying variation in etiology between grade 3 MV and grade 4 MV.

Table 6. Grade 3 or 4 Mask Ventilation Risk Factors among Standard *versus* Awake Fiberoptic Intubation Attempts

Grade 3 or 4 MV Risk Factors	Awake Fiberoptic Intubation (n = 586)	Standard Induction (n = 13,668)
≥1	460 (78)	9,644 (71)
≥2	252 (43)	4,471 (33)
≥3	97 (17)	1,431 (10)
≥4	24 (4.1)	222 (1.6)
≥5	2 (0.3)	17 (0.1)

Data are n (%).
MV = mask ventilation.

The most important result from our series of 37 grade 4 MV patients is the fact that only 1 patient required surgical airway access. Given the overlap of conditions that predispose to grade 3 MV and DI, a valid *a priori* concern would be that IMV cases may have a high incidence of impossible intubation *via* DL. Although a disproportionate share of these patients had poor views on DL, they were successfully intubated. Unfortunately, provider preoperative concern for DI may be markedly skewing our results. Out of concern for impossible ventilation and intubation, the anesthesia provider may have chosen elective awake fiberoptic intubations and thereby excluded these patients from our data set. Table 6 does demonstrate that patients undergoing elective awake fiberoptic intubation had much higher rates of the risk factors for grade 3 MV than the general population studied ($P < 0.01$). Clearly, despite our large overall sample size, we were unable to detect a large number of IMV cases and struggle to provide conclusions regarding IMV risk factors. Further studies assessing incidence, predictors, and impact of IMV are essential.

Analysis of patients with grade 3 or 4 MV and DI represents a fruitful and important effort because of the frequency observed in our population (0.37%) and a large enough series to provide meaningful data (84 cases). Limited or severely limited mandibular protrusion, thick/obese neck anatomy, a history of sleep apnea, a history of snoring, and BMI of 30 kg/m^2 or greater were identified as independent predictors. This clinical situation represents among the most feared airway outcomes: a patient in whom establishing endotracheal ventilation is difficult and the primary rescue technique, MV, is also challenging. The ability to predict this situation would offer the clinician the ability to prepare for it with alternative airway tools before engaging in anesthesia induction: laryngeal mask airway, fiberoptic intubation cart, Bullard laryngoscope, and so forth. Intuitively, the presence of a beard should not be a shared anatomical abnormality for both grade 3 MV and DI, and the data are consistent with this hypothesis. The mandibular protrusion test was the most important predictor for this outcome. This supports the theory that defects in mandibular protrusion may be a shared abnormality between DI and DMV as suggested by Takenaka *et al.*[20]

There are several limitations to our conclusions. To garner a large enough sample size, we could not introduce a data collection process or care protocol that interfered with delivery of clinical care. Despite general standardization of MV and intubation technique at our institution, we cannot guarantee that controlled and uniform conditions were applied across all the MV attempts. In addition, both the possible predictors and outcomes were recorded by providers as part of their clinical documentation responsibilities. Although the format and specificity of some elements were prospectively altered to provide more detailed data for analysis, we did not use a distinct data collection form with diagrams and extensive definitions to assist providers in accurate selection as recommended in other studies.[25] A more consistent reported incidence of grade 3 MV is a first step to predicting its occurrence. To that end, we recommend the validation of an MV scale as described by Han *et al.*[5] Our definition was more stringent than that used by Langeron and may be underestimating the incidence of clinically significant grade 3 MV as a result. Our analysis of grade 4 MV is limited by the rarity of the event more so than ambiguity in its definition. Despite reviewing more than 20,000 cases, we were able to identify only 37 occurrences and were unable to derive reliable predictors of the event. Multicenter trials combining patient populations or detailed retrospective studies of patients exhibiting IMV may be warranted.

In conclusion, we have been able to demonstrate the value of the mandibular protrusion test in predicting DMV and DMV combined with DI. We have provided confirmation of previous studies indicating the predictive value of advanced age, increased BMI, presence of a beard, and a history of snoring. Furthermore, we have been able to comment on the incidence and predictors of two more rare yet clinical worrisome situations: IMV and DMV combined with DI. We hope our data can serve to help anesthesia providers prepare for possible DMV with greater accuracy.

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