Preoperative Airway Assessment: Predictive Value of a Multivariate Risk Index

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Using readily available and objective airway risk criteria, a multivariate model for stratifying risk of difficult endotracheal intubation was developed and its accuracy compared to currently applied clinical methods. We studied 10,507 consecutive patients who were prospectively assessed prior to general anesthesia with respect to mouth opening, thyromental distance, oropharyngeal (Mallampati) classification, neck movement, ability to prognath, body weight, and history of difficult tracheal intubation. After induction of anesthesia, the laryngeal view during rigid laryngoscopy was graded and the ability of experienced anesthesia personnel to ventilate via a mask was determined. Poor intubating conditions (laryngoscopy Grade IV) and inability to achieve adequate mask ventilation were identified in 107 (1%) and 8 (0.07%) cases, respectively. Logistic regression identified all seven criteria as independent predictors of difficulty with laryngoscopic visualization. A composite airway risk index (derived from nominalized odds ratios calculated from the multivariate model) as well a simplified (0 = low, 1 = medium, 2 = high) risk weighting exhibited higher positive predictive value for laryngoscopy Grade IV at scores with similar sensitivity to Mallampati class III, as well as higher sensitivity at scores with similar positive predictive value. Compared to Mallampati class I fewer false-negative predictions were observed at a risk index value of 0. We conclude that improved risk stratification for difficulty with visualization during rigid laryngoscopy (Grade IV) can be obtained by use of a simplified preoperative multivariate airway risk index, with better accuracy compared to oropharyngeal (Mallampati) classification at both low- and high-risk levels.

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Maintenance of a patent airway is a primary responsibility of anesthesiologists. Interruption of gas exchange, for even a few minutes, can result in catastrophic outcomes such as brain damage or death. Closed claims analysis has found that the vast majority (85%) of airway-related events involve brain damage or death (1), and as many as one third of deaths attributable solely to anesthesia have been related to inability to maintain a patent airway (2).

The difficulty of achieving a patent airway varies with anatomic and other individual patient factors, and identification of the patient with a difficult airway is vital in planning anesthetic management so that endotracheal intubation and positive pressure ventilation can be achieved safely. Several clinical criteria can be routinely assessed on patients prior to anesthesia including mouth opening (3,4), Mallampati classification (5), head/neck movement (6), ability to prognath (7), thyromental distance (8), body weight (7,9), and previous history of difficult intubation. While several studies have evaluated such predictive criteria individually or in arbitrary combinations (7,10–13), there has been no sufficiently powered systematic multivariate analysis of readily available clinical variables in a large general population to determine a method of accurately stratifying the risk of encountering difficulty with intubation. Since reliability of risk stratification using multivariate models requires more than 10 outcome events per independent variable included in such analyses (14), this mandates a study of about 10,000 patients, assuming an estimated frequency of truly difficult intubation of 1% (7,15).

Accurate preoperative prediction of potential difficulty with intubation can help reduce the incidence of catastrophic complications by alerting anesthesia personnel to take additional precautions before beginning anesthesia and establishing an artificial airway. In addition, more accurate prediction of difficulty with intubation might reduce the frequency of unnecessary maneuvers (e.g., awake intubation) related to false

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positive predictions. The purpose of this study was to develop a multivariate model for stratifying risk of difficulty with laryngeal visualization using readily available and objective clinical data prospectively obtained in a large population to evaluate the relative accuracy of such a model compared to several currently applied clinical methods for preoperative prediction of the difficult airway.

Methods

After institutional Human Investigation Committee approval, we prospectively collected data on 10,507 consecutive patients scheduled to receive general anesthesia and endotracheal intubation. Age <18 yr and patients with obvious malformations of the airway who were scheduled for awake intubation were the only exclusion criteria. Body weight and previous history of difficult intubation as well as mouth opening, Mallampati classification, head/neck movement, ability to prognath, and thyromental distance were assessed preoperatively. Airway assessment was performed by the attending anesthesiologist, or in cases initially assessed by a resident or nurse anesthetist, validated by the attending anesthesiologist.

In order to derive a clinically practical predictive model, each airway assessment variable was stratified into "risk" categories. Mouth opening in patients with anterior teeth was recorded as the interincisor gap measured with the mouth fully open and was categorized as >4 cm or ≤4 cm. In edentulous patients, the intergingival distance with the mouth fully opened was recorded. Thyromental distance was measured along a straight line from the thyroid notch to the lower border of the mandibular mentum with the head fully extended and categorized as >6.5 cm, 6.0–6.5 cm, or <6.0 cm. The visibility of oropharyngeal structures was assessed in the sitting position without phonation (16) as described by Mallampati et al. (5). Assignment was made to class I when faucial pillars, soft palate, and uvula could be visualized, class II when faucial pillars and soft palate could be visualized but uvula was masked by the base of the tongue, or class III when only the soft palate could be visualized. The fourth oropharyngeal class described by Samsoon and Young (17) was not used because of excessive interobserver variability associated with this assessment (9,18). Head and neck movement was measured as described by Wilson et al. (7) by asking the patient to fully extend the head and neck. The range of motion from full extension through full flexion was categorized as >90°, 80–90°, or <80°. Ability to prognath was graded as capacity to bring the lower incisors in front of the upper incisors or the inability to perform this maneuver. Edentulous patients were assigned to the first of the latter categories. Body weight was categorized as <90 kg, 90–110 kg, or >110 kg (7,9). History of difficult intubation was quantified as absent, questionable, or definite.

The ease of gas exchange during positive pressure ventilation via face mask was assessed after induction of anesthesia and muscle relaxation. When Sellick's maneuver and rapid sequence intubation were required, mask ventilation was not attempted because of potential aspiration risk. We defined *difficult ventilation* as inability to obtain chest excursion sufficient to maintain a clinically acceptable capnogram waveform despite optimal head and neck positioning and use of muscle paralysis, use of an oral airway, and optimal application of a face mask by anesthesia personnel.

The laryngeal view was assessed with rigid laryngoscopy by experienced anesthesia personnel (>2 yr of clinical experience) using optimal head and neck positioning, forceful anterior elevation of the laryngoscope blade, use of a preferred blade by an experienced laryngoscopist, and external posterior and cephalad displacement of the larynx when required. The routine practice during this study was to attempt initial laryngoscopic visualization using a MacIntosh laryngoscope blade. Miller laryngoscope blades were generally used when difficulty was encountered or anticipated (e.g., definite history of difficult intubation). The laryngeal view was classified according to the method of Cormack and Lehane (15) as Grade I when there was full view of the glottis, as Grade II when at least the posterior commissure was visualized, as Grade IIII when none of the glottis but part or all of the epiglottis could be seen or as Grade IV when neither the laryngeal structures nor the epiglottis were visualized. In all cases the best laryngeal view was recorded as well as the laryngoscope blade used to obtain this view. Grades III and IV laryngeal views were considered to represent progressively more difficult conditions for intubation of the trachea (10,11,13,15).

The association of the individual airway assessment characteristics with the intubation findings was evaluated using the χ^2 statistic. Stepwise logistic regression analyses were performed to identify multivariate predictors of progressively difficult intubation (laryngoscopy Grades III and IV combined as well as laryngoscopy Grade IV alone). The variables in the predictor sets were found by a forward selection process such that introduction of additional variables was permitted only if the P value remained less than 0.01. The relative risk was calculated as the odds of the occurrence of difficult intubation associated with a change in the predictor variable. Factors in the final regression analyses predicting difficult intubation were then assigned a point score based on nominalization of the respective odds ratios to produce a composite airway risk scoring index. An alternative simplified airway risk index was derived by assigning a value of 0, 1, or

Table 1. Accuracy of Risk Factors in Predicting Difficulty with Tracheal Intubation

Risk factor	Laryngoscopy grade[a]	True positives	True negatives	False positives	False negatives	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
Mouth opening	≥III	169	9359	506	473	26.3	94.8	25.0	95.2
<4 cm	IV	50	9775	625	57	46.7	93.9	7.4	99.4
Thyromental distance	≥III	45	9793	72	597	7.0	99.2	38.5	94.3
<6.0 cm	IV	18	10301	99	89	16.8	99.0	15.4	99.1
Mallampati class III	≥III	287	8785	1080	355	44.7	89.0	21.0	96.1
	IV	64	9097	1303	43	59.8	87.4	4.7	99.5
Neck movement <80°	≥III	67	9705	160	575	10.4	98.4	29.5	94.4
	IV	18	10191	209	89	16.8	97.9	7.9	99.1
Inability to prognath	≥III	106	9456	409	536	16.5	95.8	20.6	94.6
	IV	28	9913	487	79	26.2	95.3	5.4	99.2
Body weight >110 kg	≥III	71	9333	532	571	11.1	94.6	11.8	94.2
	IV	14	9811	589	93	13.1	94.3	2.3	99.1
Positive history of	≥III	29	9852	13	613	4.5	99.8	69.0	94.1
difficult intubation	IV	10	10368	32	97	9.3	99.7	23.8	99.1

[a] Laryngoscopy grade categorized as either IV alone or III and IV combined.

2 to the risk factors to test how well a less complicated summation of risk would perform in predicting difficulty with intubation. Pearson's product movement correlation was used to evaluate the association between the simplified airway risk index with the composite and clinical risk index.

The individual preoperative risk factors, the composite airway risk index, and the simplified airway risk index were compared with the actual laryngoscopy grade to determine the accuracy of each in predicting difficulty with laryngeal visualization. True positives, false positives, true negatives, and false negatives as well as sensitivity, specificity, positive predictive value, and negative predictive value of each method of airway assessment were calculated using standard formulae (see Appendix).

Results

Laryngoscopy Grade III was present in 535 (5.1%) and Grade IV in 107 (1.0%) of the 10,507 patients studied. The optimal laryngeal view was obtained using the MacIntosh blade in 85.1% of the cases, and the Miller blade was used to obtain optimal visualization in the remainder. The tracheas of all patients were successfully intubated, with fiberoptic endoscopy being used in 91% of the patients exhibiting laryngoscopy Grade IV. All of the individual clinical criteria demonstrated a significant association with the occurrence of laryngoscopy Grades III and IV combined as well as laryngoscopy Grade IV alone ($P < 0.01$). Compared to the other individual criteria, Mallampati class III was associated with the greatest sensitivity but lowest specificity (Table 1). The positive predictive value of Mallampati class III was 21% for laryngoscopy Grades III and IV combined but only 4.7% for laryngoscopy Grade IV alone. With the exception of a definite history of difficult intubation, all individual criteria had low positive predictive values (2.3%–15.4% for laryngoscopy Grade IV alone and 11.8%–38.5% for laryngoscopy Grades III and IV combined).

Logistic regression analysis identified all seven variables to be independent predictors of difficult conditions for intubation of the trachea (Table 2). The presence of Mallampati class III, thyromental distance <6 cm, mouth opening <4 cm, and definite history of difficult intubation were the most significant predictors of laryngoscopy Grade IV alone, with odds ratios of 7.3, 5.8, 4.1, and 4.0, respectively. The latter variables were also the most significant predictors of laryngoscopy Grades III and IV combined.

Compared to Mallampati class III, applying the composite airway risk index derived for laryngoscopy Grade IV alone (Table 2) at a value of 10 for stratification of difficulty with laryngeal visualization results in the same sensitivity (59.8%) but greater positive predictive value (8.7% vs 4.7%) as well as greater specificity (93.6% vs 87.4%) (Figure 1), while a value of seven results in the same positive predictive value (4.7%) with greater sensitivity (80.4% vs 59.8%) but a lower specificity (83.4% vs 87.4%). The simplified airway risk index correlated well with the composite airway risk index derived for laryngoscopy Grade IV ($r = 0.92$), and stratification of difficult laryngeal visualization (Grade IV) at a simplified index value of four results in greater sensitivity (64.5% vs 59.8%), specificity (93.8% vs 87.4%) and positive predictive value (9.8% vs 4.7%) compared to Mallampati class III (Figure 1). Furthermore, the simplified airway risk index at a value of four was associated with a similar true positive ratio (sensitivity) for predicting laryngoscopy Grade IV with either the MacIntosh or Miller laryngoscope blades (66.0 vs 64.8%, respectively).

Table 2. Multivariate Predictors of Difficulty with Tracheal Intubation

Variable	Incidence (%)	Laryngoscopy grades III and IV combined		Laryngoscopy grade IV alone		Composite airway risk index weighting		Simplified airway risk index weighting[a]
		Odds ratio	P	Odds ratio	P	Laryngoscopy grades III and IV combined	Laryngoscopy grade IV alone	
Mouth opening			0.00005		0.00005			
≥4 cm	93.6					0	0	0
<4 cm	6.4	2.70	0.00005	4.09	0.00005	3	4	1
Thyromental distance			0.00005		0.00005			
>6.5 cm	89.0					0	0	0
6.0–6.5 cm	9.9	2.03	0.00005	2.31	0.0008	2	2	1
<6.0 cm	1.1	4.33	0.00005	5.81	0.00005	4	6	2
Mallampati class			0.00005		0.00005			
I	46.2					0	0	0
II	40.8	3.32	0.00005	2.18	0.0295	3	2	1
III	13.0	8.91	0.00005	7.27	0.00005	9	7	2
Neck movement			0.00005		0.00005			
>90°	91.4					0	0	0
80–90°	6.4	2.19	0.00005	2.71	0.0001	2	3	1
<80°	2.2	3.13	0.00005	2.72	0.0029	3	3	2
Ability to prognath			0.00005		0.0004			
Yes	95.1					0	0	0
No	4.9	2.48	0.00005	2.56	0.0004	2	3	1
Body weight			0.00005		0.0049			
<90 kg	77.6					0	0	0
90–110 kg	16.6	1.94	0.00005	1.45	0.1647	2	1	1
>110 kg	5.8	2.42	0.00005	2.87	0.0014	2	3	2
History of difficult intubation			0.00005		0.0020			
None	98.2					0	0	0
Questionable	1.4	2.48	0.00005	2.15	0.0367	2	2	1
Definite	0.4	9.46	0.00005	4.02	0.0021	9	4	2

[a] The risk index score represents the sum of the individual risk factor weightings (e.g., a patient with Mallampati class II, inability to prognath, weighing more than 110 kg, and with a questionable history of difficult intubation would be assigned a simplified airway risk score of 5).

Application of the composite airway risk index derived for laryngoscopy Grades III and IV combined (Table 2), however, demonstrated similar or greater positive predictive values only at index levels associated with equal or lower sensitivity compared to the Mallampati class III (Figure 2). The simplified airway risk index at a value of three demonstrated similar positive predictive value (21.9% vs 21.0%) with greater sensitivity (59.5% vs 44.7%) compared to Mallampati class III, and at values ≥4 the specificity of the simplified airway risk index exceeded that of Mallampati class III for laryngoscopy Grades III and IV combined (Figure 2). The simplified airway risk index correlated well with the composite airway risk index derived for laryngoscopy Grades III and IV combined (r = 0.95).

Based on a Mallampati class I, the incidence of false negative predictions per 10,000 cases was 72 and 10 for laryngoscopy Grades III and IV combined and for laryngoscopy Grade IV alone, respectively (Figure 3). All other risk criteria had greater false negative prediction rates, while the composite as well as the simplified airway risk indices (at values of zero) were associated with the lowest incidence of false negatives for laryngoscopy Grades III and IV combined and for laryngoscopy Grade IV alone (26 and 3 per 10,000, respectively).

Difficulty with mask ventilation, as defined above, was encountered after induction of anesthesia in eight cases (0.08%). The incidence of false positives for difficult ventilation at simplified airway risk index scores ≥4 was less (n = 262) compared with Mallampati class III (n = 1364; Table 3). No false negative predictions of difficulty with ventilation were encountered with either Mallampati class I or simplified airway risk index values of zero, and none of the other individual risk factors were associated with a true positive rate greater than 25%.

Discussion

Airway management remains an important problem in the contemporary practice of anesthesia, and preoperative assessment of the airway facilitates appropriate preparation when difficulty with ventilation or

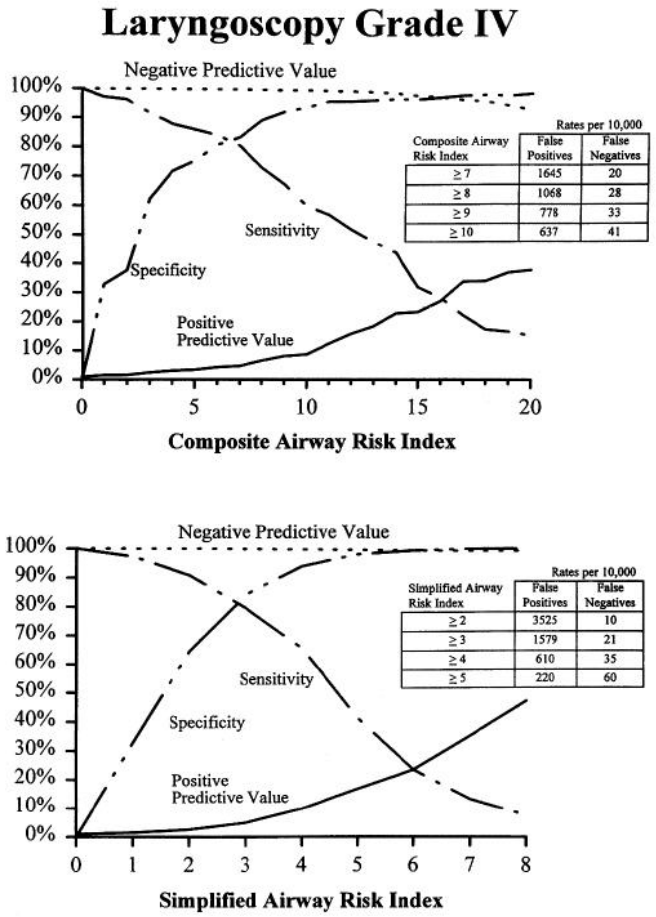

Figure 1. Sensitivity, specificity, positive, and negative predictive value of the composite airway risk index (upper panel), and simplified airway risk index (lower panel) used to predict laryngoscopy Grade IV. False positive and false negative rates are illustrated for various risk index values.

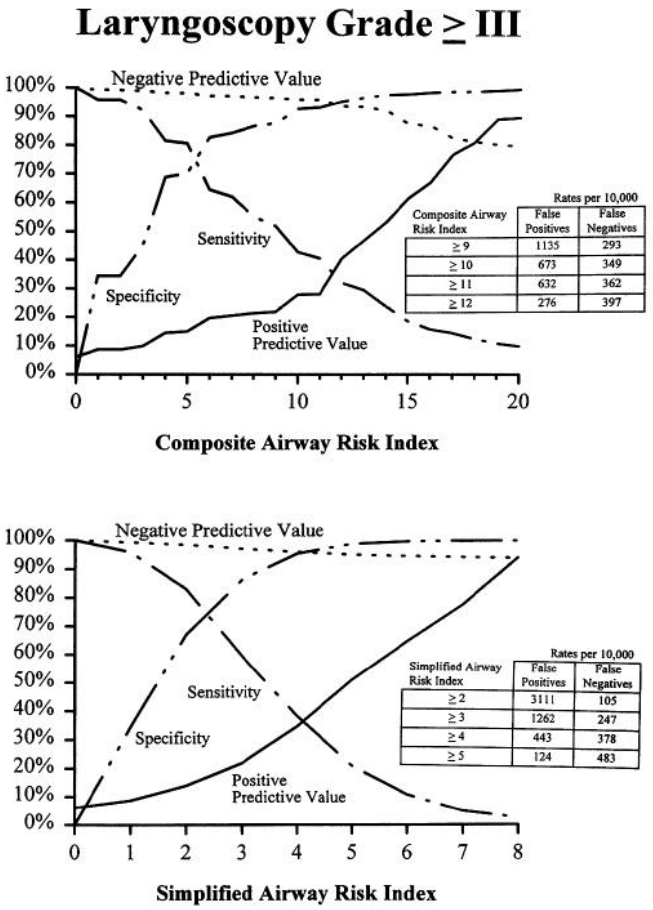

Figure 2. Sensitivity, specificity, positive, and negative predictive value of the composite airway risk index (upper panel), and simplified airway risk index (lower panel) used to predict laryngoscopy Grades III and IV combined. False positive and false negative rates are illustrated for various risk index values.

intubation is anticipated prior to initiation of anesthesia. Much information has been published on preoperative airway risk factors, although no previous study with sufficient power has examined the relative predictive ability of individual airway risk factors (including the Mallampati assessment) for occurrence of laryngoscopy Grade IV compared to a multivariable airway risk index derived form a large general population. While several studies have found that the risk for difficulty with direct laryngoscopy increases in the presence of multiple specific anatomical abnormalities (7,9,11,12), a recent study failed to demonstrate that combinations of anatomical factors were reliably predictive of laryngoscopy Grades III and IV combined (13). The negative findings of the latter study may reflect the limitations imposed by examination of fewer criteria in a smaller sample which necessitated combining laryngoscopy Grades III and IV into a single category to obtain a sufficient number of outcomes reflecting difficulty with intubation. Despite examination of 18,500 patients, Rose and Cohen (12) did not use multivariate methods nor compare the predictive utility of different levels of oropharyngeal classification with a combination of patient history and anatomical factors. A strength of our study is the examination of a population of sufficient size to justify multivariate modeling to derive a predictive index for the infrequent occurrence of the most difficult laryngeal anatomical findings (Grade IV).

Application of the multivariable composite airway risk index derived from our population stratifies the degree of difficulty encountered in visualizing the laryngeal structures better than any of the individual airway assessment criteria used to derive it. Difficulty in ventilating and successfully intubating the trachea depends on several factors besides the relative size of the tongue in the oral cavity, a major determinant of the Mallampati classifications, and our study confirms the common clinical impression that patient history, as well as other anatomical characteristics, are independent determinants of the degree of difficulty during laryngoscopy. In contrast to the widely used Mallampati classification, the multivariable model afforded a

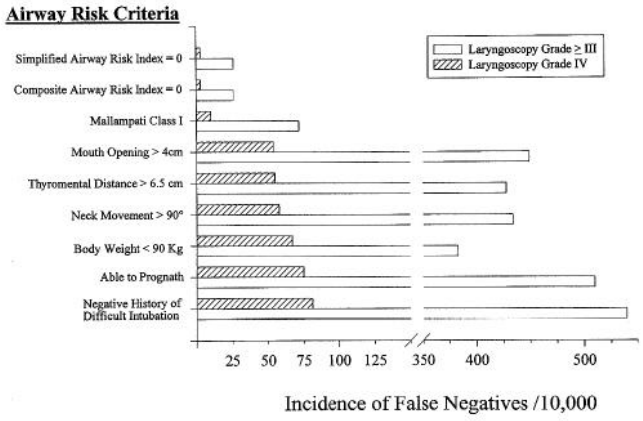

Figure 3. False negative rates associated with lowest risk categories of individual risk criteria as well as airway risk indices for predicting laryngoscopy Grade IV as well as laryngoscopy Grades III and IV combined.

Table 3. Accuracy of Risk Factors in Predicting Difficulty with Ventilation Via a Mask

Risk factor	True positives	False positives	False negatives[a]
Mouth opening			
<4 cm	2	673	6
Thyromental distance			
>6.5 cm	2	1155	6
<6.0 cm	1	116	7
Mallampati class			
I	8	5649	0
III	3	1364	5
Neck movement			
<80°	2	897	6
>90°	2	225	6
Inability to prognath	0	515	8
Body weight			
<90 kg	2	2341	6
>110 kg	1	602	7
History of difficult intubation			
None	1	181	7
Definite	1	41	7
Simplified airway risk index			
0	8	7083	0
≥2	3	1741	5
≥4	2	262	6

[a] Number of patients assessed preoperatively to be at lower risk than indicated category who subsequently presented difficulty with mask ventilation.

much greater ability to discriminate the actual occurrence of laryngeal Grade IV, with higher positive predictive value at equal sensitivity, as well as higher sensitivity at equal positive predictive value. The simplified airway risk index at values ≥4 also performed better than the Mallampati classification with better positive predictive value and higher sensitivity in predicting laryngoscopy Grade IV.

The ideal method for preoperative airway assessment should have high sensitivity and specificity and result in minimal false positive and false negative predictions. While a false positive outcome may result in a greater expenditure of time or cause inconvenience (e.g., setting up equipment such as a fiberoptic bronchoscope), the outcome of a false negative could be catastrophic (brain damage or mortality). Since no single independent criteria or combination of criteria uniformly predict all cases of abnormal laryngeal anatomy, appropriate application of a predictive index must acknowledge the dynamic relationship between sensitivity and specificity. Although high values of the derived airway risk indices result in the largest positive predictive values, this is accomplished at the cost of reduced sensitivity and a greater incidence of false negative predictions when considering index scores below the highest values. Conversely, low values of airway risk indices are associated with high sensitivity (fewer false negatives), but specificity is low with a greater number of false positives.

Our findings are clinically relevant, because application of such a preoperative scoring system (with stratification of difficulty with laryngeal visualization by using simplified airway risk index values above and below four) results both in fewer patients undergoing special airway maneuvers prompted by overestimation of airway risk as well as fewer unanticipated episodes of difficult anatomical findings during laryngoscopy (Grade IV) compared to use of the Mallampati assessment. In a center where 10,000 general anesthetics are delivered annually, the lower false positive rate of the simplified airway risk index at values ≥4 compared to the Mallampati class III potentially translates into approximately 600 fewer episodes where special precautions would be taken despite uncomplicated laryngeal anatomy, and nearly 20% fewer cases of unanticipated laryngeal Grade IV anatomy. In addition, improved stratification of laryngeal visualization is evident when comparing the simplified airway risk index at values of zero, with prediction of 46 fewer false negatives compared to the Mallampati class I for laryngoscopy Grade ≥III, as well as seven fewer episodes of unanticipated laryngoscopy Grade IV anatomy per 10,000.

While difficulty with visualization of the laryngeal structures during rigid laryngoscopy complicates airway management, in the era of fiberoptic endoscopy and other specialized airway techniques, this is probably of lesser consequence than the occurrence of difficulty with ventilation. Failure to establish an airway after induction of general anesthesia is generally associated with life-threatening sequelae only when the ability to ventilate is compromised. While improved ability to accurately predict difficulty with laryngeal

visualization is important, more substantial effects on outcome would likely be accrued from accurate preoperative prediction of difficulty with mask ventilation after induction of general anesthesia. Unfortunately, our study is underpowered to identify multivariate predictors of difficult mask ventilation using the anatomical and historical criteria we selected. Appropriate application of such a multivariate analysis would require approximately 100,000 patients, based on the incidence of difficulty with ventilation, as defined in this study.

In summary, this study indicates that use of a simple scoring system permits reliable preoperative stratification of patients into risk subsets for difficulty in visualizing laryngeal structures during rigid laryngoscopy after induction of general anesthesia. Although the multifactorial nature of the determinants of difficulty in establishing an airway inevitably contribute some imprecision to any risk scoring system, the airway risk indices derived from criteria identified as multivariate predictors were found to provide additional discriminating ability compared to individual airway risk factors, including the Mallampati classification. While a preoperative airway risk scoring system can be valuable, certainty is never possible and the potential exists for misuse of such scoring systems as quality assessment indicators. Application of such multifactorial indices for preoperative prediction of the degree of difficulty with laryngeal visualization can reduce the frequency of both unanticipated failure to visualize laryngeal structures as well as potentially unnecessary interventions related to overprediction of airway difficulty, but it remains essential for optimal patient outcome that clinicians understand the limitations of all predictive models and remain prepared to follow appropriate algorithms to avoid serious complications if unanticipated difficulty arises.

Appendix

Variables are presented that can be determined for estimating the accuracy of a diagnostic index derived from the results of a two-by-two table.

		Difficult Laryngeal Visualization		
		Positive	Negative	
		True Positive	False Positive	
Airway Risk	Positive	a	b	a+b
Predictor	Negative	c	d	c+d
		False Negative	True Negative	
		a + c	b + d	

Description	Formulae
Sensitivity or true positive ratio is the number of patients predicted to have difficult airways, who subsequently prove to have difficult laryngeal visualization, divided by the total number of patients with difficult laryngeal visualizations.	a/(a+c)
Specificity or true negative ratio is the number of patients predicted not to have difficult airways, who subsequently prove not to have difficult laryngeal visualization, divided by the total number of patients without difficult laryngeal visualizations.	d/(b+d)
Positive predictive value is the number of patients predicted to have difficult airways who subsequently prove to have difficult laryngeal visualization, divided by the total number of patients predicted to have difficult airways.	a/(a+b)
Negative predictive value is the number of patients predicted not to have difficult airways who subsequently prove not to have difficult laryngeal visualization, divided by the total number of patients predicted not to have difficult airways.	d/(c+d)

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