A model to predict difficult airway alerts after videolaryngoscopy in adults with anticipated difficult airways – the VIDIAC score

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Summary
A model to classify the difficulty of videolaryngoscopic tracheal intubation has yet to be established. The videolaryngoscopic intubation and difficult airway classification (VIDIAC) study aimed to develop one based on variables associated with difficult videolaryngoscopic tracheal intubation. We studied 374 videolaryngoscopic tracheal intubations in 320 adults scheduled for ear, nose and throat or oral and maxillofacial surgery, for whom airway management was expected to be difficult. The primary outcome was whether an anaesthetist issued a ‘difficult airway alert’ after videolaryngoscopy. An alert was issued after 183 (49%) intubations. Random forest and lasso regression analysis selected six intubation-related variables associated with issuing an alert: impaired epiglottic movement; increased lifting force; direct epiglottic lifting; vocal cords clearly visible; vocal cords not visible; and enlarged arytenoids. Internal validation was performed by a 10-fold cross-validation, repeated 20 times. The mean (SD or 95%CI) area under the receiver operating characteristic curve was 0.92 (0.05) for the cross validated coefficient model and 0.92 (0.89–0.95) for a simplified unitary score (VIDIAC score with component values of −1 or 1 only). The calibration belt for the coefficient model was consistent with observed alert probabilities, from 0% to 100%, while the unitary VIDIAC score overestimated probabilities < 20% and underestimated probabilities > 70%. Discrimination of the VIDIAC score for patients more or less likely to be issued an alert was better than discrimination by the Cormack–Lehane classification, with mean (95%CI) areas under the receiver operating characteristic curve of 0.92 (0.89–0.95) vs. 0.75 (0.70–0.80), respectively, p < 0.001. Our model and score can be used to calculate the probabilities of difficult airway alerts after videolaryngoscopy.

Introduction
Difficult airway management causes adverse events and liability claims against anaesthetists [1–3]. Videolaryngoscopy has improved airway management and permits image and video documentation in electronic health records [4–7].

A prospectively derived classification system for difficult videolaryngoscopic intubation does not yet exist. The
Cormack–Lehane classification and its modification by Yentis and Cook, and the percentage of glottic opening are most often used for this purpose [8–11]. These scores, however, were designed to rate the laryngeal view achieved by direct laryngoscopy and might be unsuitable for videolaryngoscopy [12–14].

Guidelines recognise two components of difficult videolaryngoscopic tracheal intubation: impaired view of the glottis; and difficult advancement of the tube through the glottis into the trachea [15, 16]. Attempts have been made to combine these components in a single score [17–19].

The videolaryngoscopic intubation and difficult airway classification (VIDIAC) study aimed to prospectively develop a multivariable lasso regression model that uses intubation-related variables to predict difficult airway alerts issued by the anaesthetist after videolaryngoscopy. Secondary aims were to compare the discrimination of the VIDIAC and Cormack–Lehane classifications for difficult airway alerts and to assess the discrimination of the model for transition to a hyperangulated blade.

Methods
The Hamburg Medical Association ethics committee approved this pre-registered study, which we conducted and reported as standard [20, 21]. Participants gave written informed consent.

We studied adults aged ≥18 y in whom we expected difficult airway management, with tracheal intubation aided by videolaryngoscopy. We did not study patients in whom awake tracheal intubation was planned or pregnant women. Participants were scheduled for ear, nose and throat surgery or oral and maxillofacial surgery between 1 April 2019 and 3 April 2020. We assessed airways from clinical history (for instance, radiotherapy or difficult intubation) and by clinical examination (for instance, the upper lip bite test, flexible nasendoscopy and the simplified airway risk index) [22–24].

We recorded study airway assessments and outcome variables separately from clinical notes during the study period to allow multiple independent assessments for participants who had multiple anaesthetics.

We stipulated one aspect of anaesthetic care; initial videolaryngoscopy with a Macintosh-type blade (C-MAC™, Karl Storz, Tuttlingen, Germany) without direct epiglottic lifting. Anaesthetists chose how to induce anaesthesia, position the patient, manipulate the airway and intubate the trachea, including the use of airway adjuncts and conversion to different intubation techniques and devices, for instance direct epiglottic lifting and transition to hyperangulated blades. The anaesthetist and two observers independently assessed intubation-related characteristics during or directly following tracheal intubation. We used Fleiss’ $\kappa$ to calculate the agreement between their ratings of each factor before we developed the model.

The primary outcome was that the anaesthetist expected future videolaryngoscopic tracheal intubations to be difficult, which was documented as a difficult airway alert. We also analysed: hyperangulated blade use; bronchoscopic intubation; difficult videolaryngoscopy; difficult intubation as defined previously [15]; the number of laryngoscopy attempts and the number of intubation attempts; first pass success (one attempt at laryngoscopy and intubation); time to tracheal intubation; first end-tidal carbon dioxide partial pressure after intubation; airway-related adverse events; length of hospital stay and death before hospital discharge. We defined airway-related adverse events as laryngospasm, bronchospasm, airway or oral trauma, including bleeding and dental injury, glottic swelling or corticosteroids to reduce swelling risk, oesophageal intubation, oxygen saturations < 93% or unanticipated ICU admission [2].

We selected variables for model development that we thought might be associated with subsequent difficult airway alerts after videolaryngoscopy: small mouth opening (interincisor gap ≤ 2.5 cm); maxillofacial abnormality; cervical spine immobility or instability; increased risk of rapid desaturation [15, 25]; rapid sequence intubation; glottic view with videolaryngoscopy; impaired epiglottic movement with laryngoscopy; increased epiglottic lifting force; direct lifting; obscuring upper airway lesions, including glottic pathology such as arytenoid lesions; epiglottis dysmorphia or lesions; obscuring bleeding or secretions; difficult orotracheal tube alignment; ease of tube advancement; characteristics of the tracheal tube and airway adjuncts; manoeuvres to improve glottic view and tracheal tube advancement; and facemask ventilation [8, 9, 11, 17, 18, 25, 26].

We categorised the best view of the glottis displayed on the videolaryngoscope screen during initial laryngoscopy as: vocal cords completely visible (1); part of the cords visible (2a); posterior cords only just visible (2b); arytenoids but not cords visible (2c); epiglottis but no glottis visible (3); laryngeal structures not visible (4) [8, 9, 11]. We grouped views as ‘clearly visible’ (1 and 2a), ‘only just visible’ (2b) or ‘not visible’ (2c, 3 or 4).

We decided to include 400 anaesthetics to reach a sample size of 381, assuming 5% dropouts. We assumed a difficult airway alert rate after videolaryngoscopy of 0.45 (determined on planned interim analysis after 100 cases), a shrinkage of predictor effects of 10% and a small optimism.
in apparent model fit. We assumed a Cox-Snell-R² of 0.5 and 16 candidate predictors to be appropriate [27].

We developed a multivariable prediction model for difficult airway alerts after videolaryngoscopy. We used 100,000 random forest analysis decision trees to select variables for the model fitting. We calculated Gini impurity to quantify the importance of intubation-related variables to correctly classify patients with an alert [28]. We used least absolute shrinkage selector operator (lasso) regression for variable selection, model development and internal validation. We first determined the shrinkage parameter λ with a 10-fold cross validation. Coefficients that were not shrunk to zero were considered relevant predictors. We then estimated shrunk β-coefficients with 10-fold lasso regression cross validation, repeated 20 times, from which we report the discrimination, defined by the mean (SD) area under the receiver operating characteristic curve of the best fitting lasso regression model and we plotted the calibration belt [29–31].

In addition to this coefficient model, we rounded the shrunk β-coefficients to develop two simplified scores; a weighted integer score, with component values of −2, −1, 1 or 2; which we further simplified as a unitary VIDIAC score with component values of −1, or 1 only.

We compared discrimination of the VIDIAC score with the Cormack–Lehane classification [32]. We applied the VIDIAC score, calculated from association with difficult airway alerts after videolaryngoscopy, to transition to a hyperangulated blade. We calculated the probabilities for difficult airway alerts for different VIDIAC score values respecting the corresponding intercept.

We used SPSS 25 (IBM Inc., Armonk, NY, USA) and R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria) for analyses.

### Results

We analysed 374 anaesthetics in 320 participants (Fig. 1 and Table 1). There were 81 anaesthetists, median (IQR [range]) age 30 (28–32 [26–51]) years, with 18 (8–40 [1–168]) months anaesthetic experience. Within the study, 52 (64%) anaesthetists said they had performed at least 25 videolaryngoscopic intubations.

Anaesthetists issued a difficult airway alert after 183/374 (49%) tracheal intubations (Table 2). Agreement between rater’s assessments of all co-variables was substantial (mean Fleiss’ κ range between 0.72 and 1.00). Six variables were independently associated with issuing an

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**Table 1** Characteristics before and during 374 videolaryngoscopic tracheal intubations in 320 participants with expected difficult airways. Values are mean (SD), number (proportion) or median (IQR [range]).

| Characteristic                      | Value                                                                 |
|-------------------------------------|----------------------------------------------------------------------|
| Age; y                              | 61.5 (13.8)                                                          |
| BMI; kg.m⁻²                         | 25.9 (6.4)                                                           |
| Sex; male                           | 260 (70%)                                                            |
| ASA physical status                 | 21 (6%)                                                              |
| Previous neck dissection            | 112 (30%)                                                            |
| Previous tracheostomy              | 101 (27%)                                                            |
| Previous neck radiotherapy          | 95 (25%)                                                             |
| Previous awake tracheal intubation  | 64 (17%)                                                             |
| Previous mouth floor resection      | 54 (14%)                                                             |
| Existing anaesthesia alert card     | 48 (13%)                                                             |
| Mallampati class                    | 42 (11%)                                                             |
| Supraglottic tumour                 | 94 (25%)                                                             |
| Glottic tumour                      | 36 (10%)                                                             |
| Simplified airway risk index        | 4 (3–6 [0–11])                                                      |
| Could not bite upper lip            | 143 (38%)                                                            |
| Type of surgery                     |                                                                      |
| Laryngopharyngeal                   | 151 (40%)                                                            |
| Mandible                            | 89 (24%)                                                             |
| Neck, maxillofacial                 | 76 (20%)                                                             |
| Ear, nose                           | 35 (9%)                                                              |
| Dentoalveolar                       | 23 (6%)                                                              |
| Nasal intubation                    | 113 (30%)                                                            |
| Rapid sequence intubation           | 29 (8%)                                                              |

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Table 2  Rates of the primary outcome (difficult airway alert after videolaryngoscopy) and secondary outcomes after 374 tracheal intubations in adults with anticipated difficult airways. Values are number (proportion), median (IQR [range]) or mean (SD).

| Outcome                                                                 | 183 (49%)                  | 114 (31%)                  | 76 (20%)                   |
|------------------------------------------------------------------------|----------------------------|----------------------------|---------------------------|
| Difficult airway alert after videolaryngoscopy                         |                            |                            |                           |
| Difficult intubation                                                   |                            |                            |                           |
| Difficult videolaryngoscopy                                            |                            |                            |                           |
| Transition to a hyperangulated blade                                   |                            |                            |                           |
| Laryngoscopic attempts                                                 | 251 (67%)                  | 91 (24%)                   | 32 (9%)                   |
| 1                                                                     |                            |                            |                           |
| 2                                                                     |                            |                            |                           |
| >2                                                                    |                            |                            |                           |
| Intubation attempts                                                    |                            |                            |                           |
| 1                                                                     | 260 (70%)                  |                            |                           |
| 2                                                                     | 48 (13%)                   |                            |                           |
| >2                                                                    | 66 (18%)                   |                            |                           |
| First pass success                                                     | 195 (52%)                  |                            |                           |
| Time to tracheal intubation; s                                         | 86 (42–175 [15–1177])     |                            |                           |
| First end-tidal carbon dioxide after intubation; mmHg                   | 36.1 (8.4)                 |                            |                           |
| Airway-related adverse events                                          | 68 (18%)                   |                            |                           |
| Length of hospital stay; days                                          | 3 (2–7 [0–91])             |                            |                           |
| Deaths in hospital                                                     | 2 (1%)                     |                            |                           |

Table 3  Multivariable lasso regression model for independent association with the issue of a difficult airway alert after intubation. Values are point estimates, median (IQR [range]), mean (SD) or mean (95%CI).

| Variables                              | β-coefficient | Integer score |
|----------------------------------------|---------------|---------------|
| Intercept*                             | −1.53         | −2            | −1            |
| Impaired epiglottic movement           | 1.15          | 1             | 1             |
| Increased lifting force                | 1.16          | 1             | 1             |
| Direct epiglottic lifting              | 1.85          | 2             | 1             |
| Vocal cords                            |               |               |               |
| Clearly visible (1 or 2a view)         | −1.05         | −1            | −1            |
| Only just visible (2b view)            | Shrunken to zero |               |               |
| Not visible (2c or more)               | 2.04          | 2             | 1             |
| Enlarged arytenoids                    | 1.77          | 2             | 1             |
| Range (without intercept)              | −1.05 to 7.97 | −1 to 8       | −1 to 5       |
| Range (with intercept*)                | −2.59 to 6.43 | −3 to 6       | −2 to 4       |
| Probability                            | 0.43 (0.07–0.90 [0.07–1.00]) | 0.47 (0.05–0.88 [0.05–1.00]) | 0.50 (0.12–0.73 [0.12–0.98]) |
| AUC                                    | 0.92 (0.05)   | 0.92 (0.89–0.95) | 0.92 (0.89–0.95) |

AUC, area under the receiver operating characteristic curve.
*The intercept must be included when calculating the probabilities.
labels. The vertical axis is the net benefit that outlines the relation between benefit and harm. The figure illustrates net benefit from using the coefficient model and VIDIAC score, compared with labelling all airways difficult or no airways difficult. Three threshold probabilities are highlighted: 50% (VIDIAC score 1), 73% (VIDIAC score 2), 88% (VIDIAC score 3), which represent a physician who would want to avoid the `difficult airway´ label until probabilities of 50%, 73% or ≥ 88% were reached, respectively.

Based on the calculated probabilities of difficult airway alerts we propose to grade the VIDIAC score as follows: easy, –1 or 0 points (12–27% probabilities); moderate, 1 point (50% probability); hard, 2 points (73% probability); severe, ≥ 3 points (> 88% probabilities) (online Supporting Information, Figure S2). The corresponding sensitivity and specificity are given in online Supporting Information (Table S1).

Figure 4 illustrates possible blade-epiglottis interactions and videolaryngoscope camera views as well as the corresponding unitary VIDIAC score for issuing difficult airway alerts after videolaryngoscopy.

The VIDIAC score discriminated participants more or less likely to have secondary laryngoscopy with hyperangulated blades, with a mean (95%CI) area under the receiver operating characteristic curve of 0.95 (0.93–0.97).

**Discussion**

We have developed a multivariable model and score that associates intubation-related characteristics with subsequent issuing of a difficult airway alert after videolaryngoscopy, tailored to be used as a classification tool to grade difficult
videolaryngoscopic intubation. Components of the VIDIAC score and the calculated probability can be stored with an image of the laryngeal inlet or a video from the videolaryngoscope camera [7]. The coefficient model and VIDIAC score could help anaesthetists plan subsequent anaesthetics. While the VIDIAC score is intuitive and easy to use for manual scoring, the coefficient model or weighted integer score might be more accurate.

We assessed difficult videolaryngoscopy and difficult intubation, as recommended for rating the difficulty of videolaryngoscopic intubation [5, 15, 16]. The six characteristics associated with a difficult airway alert after videolaryngoscopy are derived from the blade-epiglottis interaction, the view of the glottis or narrowing of the posterior laryngeal inlet.

Point pressure on the hyoepiglottic ligament, transmitted by the tip of the laryngoscope, lifts the epiglottis up as described by Macintosh in 1943 [33]. If this mechanism is altered, anterosuperior epiglottic movement may be restricted. We tested all previously outlined landmarks (corresponding with a grade 1, 2a, 2b, 2c, 3 and 4 view) independently. Failure to view the vocal cords, even if the arytenoids were seen, had the strongest association with the issuing of a difficult airway alert, while alerts were less frequent after a good view of the cords than a partial view. The posterior laryngeal inlet is compromised by the other factor, enlarged arytenoids, which restrict glottic view and tube advancement.

Our study took place in a single centre in a particular group of patients with a particular videolaryngoscope protocol: we do not know to what extent our findings will be replicated elsewhere or in patients without anticipated difficult airways having operations other than ear, nose and throat surgery or oral and maxillofacial surgery. We are currently conducting external validation studies in patients with other characteristics and operations. We also plan to study the diagnostic performance of the VIDIAC score with hyperangulated blades.

We think that rather than dichotomise patients as having or not having difficult videolaryngoscopic tracheal intubation, which one might do at a particular VIDIAC threshold, it would be better to grade anticipated difficulty based on the probability of difficult airway alerts.

Figure 4  The VIDIAC score is comprised of: E, the interaction between the blade tip and epiglottis; V, the best view of the vocal cords from the blade camera; and A, enlargement of the arytenoids. Illustration by Rasmus Borkamp, Hamburg, Germany.
In conclusion, we have developed a multivariable lasso regression model and simplified VIDIAC score that associates videolaryngoscopic intubation characteristics with subsequent issuing of a difficult airway alert. The VIDIAC score demonstrated high discrimination and outperformed the Cormack–Lehane classification. Further research might explore the relative merits of ordered categories of anticipated videolaryngoscopy difficulty.

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Supporting Information
Additional supporting information may be found online via the journal website.

**Figure S1.** Probabilities of the unitary VIDIAC score compared with the probabilities of the coefficient model and weighted score to predict difficult airway alerts after videolaryngoscopy.

**Figure S2.** Proposed probability-based grading of the VIDIAC score. Illustration by Rasmus Borkamp, Hamburg, Germany.

**Table S1.** Specification of the unitary VIDIAC score and decision thresholds.