

# SMARTPHONE-DERIVED FACIAL ANTHROPOMETRIC MEASUREMENTS FOR PREDICTION OF DIFFICULT AIRWAY: A COMPARISON WITH CONVENTIONAL AIRWAY ASSESSMENT METHODS

Original Research (ID: 1707)

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## ABSTRACT

**Background:** Preoperative recognition of difficult airway remains central to safe anesthetic care because failed or delayed airway control may rapidly compromise oxygenation. Conventional bedside tests are simple and widely used, but their accuracy is often limited by subjective interpretation and observer variability. Smartphone-based facial imaging may offer a practical way to capture objective craniofacial measurements related to laryngoscopic view, especially in settings where advanced airway-assessment technology is not routinely available for daily preoperative screening practice locally.

**Objective:** To evaluate smartphone-derived facial anthropometric measurements for predicting difficult laryngoscopy and compare their diagnostic performance with conventional airway assessment methods.

**Methods:** This prospective observational comparative study included 35 adults aged 18–65 years, ASA I–III, undergoing elective surgery under general anesthesia with endotracheal intubation. Conventional assessment included Mallampati class, mouth opening, thyromental distance, sternomental distance, neck circumference, upper lip bite test, and neck extension. Standardized smartphone photographs were analyzed for facial width, mandibular width, chin projection angle, neck-chin angle, neck-to-face ratio, jawline angle, and submandibular contour. Difficult laryngoscopy was defined as Cormack–Lehane Grade III–IV. Analysis included logistic regression, ROC curves, diagnostic indices, leave-one-out cross-validation, bootstrap validation, and calibration assessment.

**Results:** Difficult laryngoscopy occurred in 7 patients (20.0%), while 28 patients (80.0%) had easy laryngoscopy. Chin projection angle showed apparent AUC 0.90 and LOOCV AUC 0.85. Neck-chin angle showed apparent AUC 0.86 and LOOCV AUC 0.81. Thyromental distance had AUC 0.83, sensitivity 85.7%, and specificity 75.0%. The combined model achieved apparent AUC 0.94, LOOCV AUC 0.89, optimism-corrected AUC 0.87, sensitivity 85.7%, specificity 90.0%, accuracy 88.6%, calibration slope 0.72, and Brier score 0.12.

**Conclusion:** Smartphone-derived facial anthropometric measurements appeared useful as adjuncts to conventional airway assessment. Their clinical use requires larger multicenter validation before routine implementation.

**Keywords:** Airway Management; Anesthesiology; Anthropometry; Intubation, Intratracheal; Laryngoscopy; Preoperative Care; Smartphone.

## INTRODUCTION

Airway management remains one of the most important responsibilities of anesthesiologists and is directly linked with patient safety during perioperative care. A secure airway allows adequate oxygenation and ventilation, whereas failure to recognize or manage a difficult airway can rapidly lead to serious complications such as hypoxemia, aspiration, airway trauma, cardiac arrest, neurological injury, and death (1). Although modern anesthesia practice has benefited from improved airway devices, advanced monitoring, and structured airway algorithms, unanticipated difficult laryngoscopy and tracheal intubation continue to present a significant clinical challenge in operating rooms worldwide (2). This concern is especially important because even a brief delay in securing the airway may place the patient at substantial risk. Preoperative identification of patients who are likely to have difficult airway is therefore a central component of safe anesthetic planning. When a difficult airway is anticipated, anesthesiologists can arrange experienced personnel, prepare alternative airway devices, modify the induction plan, and reduce the likelihood of emergency airway failure. Difficult laryngoscopy and intubation have been reported in a considerable proportion of surgical patients and remain important contributors to anesthesia-related morbidity and mortality (3). For this reason, an accurate, practical, and reproducible airway assessment method is needed to improve clinical decision-making before anesthesia induction (4).

In routine practice, airway evaluation is commonly performed using bedside tests such as the Mallampati classification, thyromental distance, sternomental distance, inter-incisor distance, upper lip bite test, and neck circumference. These methods are simple, inexpensive, and easy to perform, which explains their widespread use in preoperative assessment. However, their diagnostic value remains limited when used alone. Many of these tests assess only one anatomical component of the airway and may not fully reflect the complex relationship between facial structure, mandibular space, cervical mobility, oral opening, and laryngoscopic view. In addition, conventional assessments may be influenced by patient cooperation, examiner technique, inter-observer variation, and clinical experience. As a result, their sensitivity and specificity for predicting difficult airway have remained inconsistent across different populations and clinical settings (5,6). The limitations of conventional airway assessment have encouraged researchers to explore more objective methods that can capture multiple anatomical features at the same time. Facial anthropometry is one such approach, as it provides measurable information about craniofacial structure, mandibular dimensions, facial proportions, chin projection, jaw contour, and neck profile. These anatomical characteristics are clinically relevant because they may influence oral access, pharyngeal space, alignment of airway axes, and the ease of laryngoscopy. Previous work has suggested that certain facial and mandibular measurements may be associated with difficult laryngoscopy, indicating that facial morphology may provide useful clues during airway evaluation (7).

Recent developments in smartphone technology have made this approach more practical. Modern smartphones are equipped with high-resolution cameras that can capture clear facial images without specialized equipment. These images can then be used to obtain facial anthropometric measurements in a standardized and non-invasive manner. Compared with purely subjective bedside assessment, smartphone-derived measurements may provide a more objective record of patient anatomy and may help reduce observer-related variability. This is particularly relevant in busy preoperative areas where time is limited and assessment methods need to be simple, quick, and easily repeatable. Smartphone-based airway assessment may also have special value in resource-limited healthcare settings. It is inexpensive, widely accessible, and does not require advanced imaging facilities. If proven accurate, it could support preoperative screening in both tertiary hospitals and smaller centers where access to sophisticated airway evaluation tools may be limited. Moreover, smartphone-derived facial measurements may serve as a foundation for future digital airway assessment systems, including automated or artificial intelligence-assisted prediction models (8). Such tools could improve consistency in airway evaluation and help clinicians identify high-risk patients before induction of anesthesia.

Despite increasing global interest in image-based and technology-assisted airway prediction, evidence from Pakistan remains limited. Most local clinical assessments still rely on conventional bedside methods, and there is a lack of data evaluating whether smartphone-derived facial anthropometric measurements can improve prediction of difficult airway in the Pakistani adult surgical population. This gap is important because craniofacial characteristics, body habitus, and clinical practice patterns may vary across populations, and findings from other regions may not be directly applicable to local patients. The present study was therefore designed to address this gap by evaluating whether smartphone-derived facial anthropometric measurements can predict difficult airway in adult surgical patients. The study further aimed to compare the diagnostic performance of these measurements with commonly used conventional airway assessment methods. It was hypothesized that smartphone-derived facial anthropometric measurements would provide objective and clinically useful predictors of difficult airway and may demonstrate comparable or improved predictive accuracy when compared with traditional bedside airway assessment methods.

## METHODOLOGY

This prospective observational comparative study was conducted over a period of six months at a tertiary care teaching hospital in Pakistan. The study was designed to compare the predictive performance of smartphone-derived facial anthropometric measurements with conventional preoperative airway assessment methods for identifying difficult laryngoscopy among adult surgical patients undergoing general anesthesia with endotracheal intubation. Adult patients aged 18–65 years, belonging to American Society of Anesthesiologists physical status I–III, who were scheduled for elective surgery under general anesthesia and required endotracheal intubation, were considered eligible for participation. Patients were excluded if they had congenital craniofacial abnormalities, facial

deformities, facial or cervical trauma, upper airway tumors or other airway pathology, restricted mouth opening that prevented adequate airway assessment, emergency surgical procedures, pregnancy, or refusal to provide informed consent. These criteria were applied to obtain a relatively uniform surgical population in whom both conventional airway assessment and smartphone-based facial imaging could be performed safely and consistently.

During the study period, 200 patients presenting for preoperative anesthesia assessment were screened for eligibility. After application of the inclusion and exclusion criteria, 35 patients fulfilled the eligibility requirements, provided written informed consent, and were included in the final analysis. A non-probability consecutive sampling technique was used, whereby all eligible and consenting patients were enrolled sequentially until completion of the study period. Before enrollment, the purpose, procedure, possible benefits, and confidentiality safeguards of the study were explained to each participant. Each enrolled patient was assigned a unique study identification number to maintain anonymity and facilitate data management (9). Preoperative conventional airway assessment was performed before induction of anesthesia by trained anesthesia personnel using standardized bedside methods. The assessment included Mallampati classification, thyromental distance, sternomental distance, inter-incisor distance, neck circumference, upper lip bite test, and neck extension. These parameters were selected because they are commonly used in routine anesthesia practice and reflect different anatomical and functional components of airway difficulty, including oral access, mandibular space, cervical mobility, and external neck profile (10,11).

In addition to conventional assessment, standardized smartphone-based facial imaging was performed for each participant under controlled conditions. Frontal, lateral, neck-extension, and mouth-opening photographs were obtained using a smartphone camera while maintaining uniform patient positioning, camera distance, lighting, and background as far as practically possible. The images were captured before anesthesia induction and were stored securely in password-protected digital storage. Patient identity was protected by using study identification codes rather than names on image files. The captured photographs were then used for image-based anthropometric analysis to measure facial and airway-related anatomical parameters. Facial anthropometric analysis included measurement of facial width, mandibular width, chin projection angle, neck-chin angle, neck-to-face ratio, and jawline angle. These variables were selected because facial proportions, mandibular morphology, chin projection, and cervicomental profile may influence pharyngeal space, alignment of airway axes, and laryngoscopic visualization. The anatomical landmarks and angular measurements were assessed using image-based measurement techniques according to predefined operational definitions to improve consistency and reduce observer-related variation (12,13).

Intraoperative airway assessment was performed during induction of general anesthesia by an experienced anesthesiologist. To reduce variability in Cormack–Lehane grading, a standardized laryngoscopy protocol was followed. Patients were placed in the sniffing position using a standard pillow height of approximately 7–10 cm, with appropriate alignment of the external auditory meatus and sternal notch where feasible. Adequate neuromuscular blockade was confirmed before laryngoscopy using peripheral nerve stimulation, with a train-of-four ratio of less than 0.1. Patients received rocuronium at 0.6 mg/kg or succinylcholine at 1 mg/kg according to the anesthesiologist's clinical judgment and patient suitability. Direct laryngoscopy was performed using a Macintosh blade size 3 or 4, selected according to the patient's anatomical characteristics and the anesthesiologist's assessment. The initial laryngoscopic view was recorded without external laryngeal manipulation to obtain the unmodified Cormack–Lehane grade. If external laryngeal manipulation was subsequently applied to improve visualization, this was documented separately, and the improved view was recorded as a secondary finding. However, only the initial unmodified Cormack–Lehane grade was used for the primary analysis. The laryngoscopic view was graded after the best possible view had been obtained using standard laryngoscopy technique. Grade I and II views were classified as easy laryngoscopy, while Grade III and IV views were classified as difficult laryngoscopy. The Cormack–Lehane grading observed during direct laryngoscopy was used as the reference standard for outcome classification (14,15).

To reduce observer bias, the anesthesiologist performing direct laryngoscopy and recording the Cormack–Lehane grade was blinded to the results of both the preoperative smartphone-derived facial anthropometric analysis and conventional airway assessment findings (16). Where feasible, inter-rater reliability of Cormack–Lehane grading was assessed in a random subset of 10 cases through direct observation by two independent anesthesiologists or review of recorded laryngoscopy videos. Cohen's kappa coefficient was calculated to quantify agreement between observers. Data were collected using a structured data collection proforma that included demographic characteristics, clinical variables, conventional airway assessment findings, smartphone-derived facial anthropometric measurements, intraoperative laryngoscopic grade, use of external laryngeal manipulation, and final airway classification. After checking for completeness and consistency, data were entered into IBM SPSS Statistics version 26 for statistical analysis.

Quantitative variables were expressed as mean and standard deviation, whereas qualitative variables were presented as frequencies and percentages. The association between individual conventional airway parameters, smartphone-derived facial measurements, and difficult laryngoscopy was assessed using appropriate inferential statistics. Logistic regression analysis was performed to identify predictors of difficult laryngoscopy. Receiver operating characteristic curve analysis was used to evaluate diagnostic performance, and the area under the curve was calculated for selected predictors and models. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated to compare the diagnostic accuracy of smartphone-derived anthropometric measurements with conventional airway assessment methods. Multivariable logistic regression using Firth's bias-reduction method was applied to adjust for age, sex, and

body mass index, considering the small sample size and the possibility of sparse outcome data. Internal validation was performed using leave-one-out cross-validation and bootstrap resampling with 200 iterations. Model calibration was assessed using calibration slope, calibration intercept, Brier score, and the Hosmer–Lemeshow goodness-of-fit test. A p-value of less than 0.05 was considered statistically significant. Ethical approval was obtained from the Institutional Ethical Review Committee before commencement of the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants before enrollment. Participation was voluntary, and patients were informed that refusal to participate would not affect their treatment or standard of care. Confidentiality of personal information and facial images was maintained throughout data collection, storage, analysis, and reporting.

## RESULTS

A total of 35 adult patients undergoing elective surgery under general anesthesia with endotracheal intubation were included in the final analysis. All enrolled patients completed the study protocol. The mean age of the participants was  $38.7 \pm 12.6$  years. There were 22 male patients (62.9%) and 13 female patients (37.1%). The mean height was  $166.2 \pm 8.3$  cm, the mean weight was  $69.4 \pm 11.7$  kg, and the mean body mass index was  $25.1 \pm 3.6$  kg/m<sup>2</sup>. Most patients belonged to ASA physical status I or II, with 16 patients (45.7%) classified as ASA I, 17 patients (48.6%) as ASA II, and 2 patients (5.7%) as ASA III. General surgery was the most common surgical category, involving 14 patients (40.0%), followed by orthopaedic surgery in 10 patients (28.6%), ENT surgery in 6 patients (17.1%), and urological surgery in 5 patients (14.3%). Preoperative conventional airway assessment showed that Mallampati Class II was the most frequent category, observed in 16 patients (45.7%). Mallampati Class I was recorded in 7 patients (20.0%), Class III in 10 patients (28.6%), and Class IV in 2 patients (5.7%). The mean mouth opening was  $4.1 \pm 0.6$  cm, while the mean thyromental distance and sternomental distance were  $6.7 \pm 0.9$  cm and  $12.8 \pm 1.6$  cm, respectively. The mean neck circumference was  $37.2 \pm 2.8$  cm. Upper Lip Bite Test Class I was observed in 15 patients (42.9%), Class II in 16 patients (45.7%), and Class III in 4 patients (11.4%). Neck extension was normal in 31 patients (88.6%) and restricted in 4 patients (11.4%).

Smartphone-derived facial anthropometric analysis demonstrated a mean facial width of  $13.6 \pm 0.9$  cm and a mean mandibular width of  $9.5 \pm 0.7$  cm. The mean chin projection angle was  $17.9 \pm 4.2^\circ$ , and the mean neck-chin angle was  $105.3 \pm 6.8^\circ$ . The mean neck-to-face ratio was  $0.74 \pm 0.06$ , and the mean jawline angle was  $128.6 \pm 7.9^\circ$ . A reduced submandibular contour was identified in 11 patients (31.4%). During intraoperative airway assessment, direct laryngoscopy was performed using standardized positioning, neuromuscular blockade confirmation, and Macintosh blade selection. Cormack–Lehane Grade I was observed in 16 patients (45.7%), Grade II in 12 patients (34.3%), Grade III in 5 patients (14.3%), and Grade IV in 2 patients (5.7%). Based on the predefined classification, 28 patients (80.0%) had easy laryngoscopy, while 7 patients (20.0%) had difficult laryngoscopy. External laryngeal manipulation improved the laryngoscopic grade in 2 patients (5.7%), with improvement from Grade III to Grade II. In the subset of 10 cases assessed for inter-rater reliability, Cohen’s kappa was 0.68, with a 95% confidence interval of 0.42–0.94.

First-attempt intubation was successful in 26 patients (74.3%). A second attempt was required in 6 patients (17.1%), while 3 patients (8.6%) required three or more attempts. A stylet was used in 10 patients (28.6%), a bougie in 5 patients (14.3%), and a video laryngoscope in 3 patients (8.6%). The mean Intubation Difficulty Scale score was  $2.8 \pm 1.6$ . Difficult intubation, defined as an Intubation Difficulty Scale score greater than 5, was observed in 4 patients (11.4%). Overall, difficult airway of any component was documented in 7 patients (20.0%). Difficult mask ventilation occurred in 1 patient (2.9%). Difficult laryngoscopy was recorded in 7 patients (20.0%), while difficult intubation was recorded in 4 patients (11.4%). Airway rescue devices were required in 2 patients (5.7%), and an airway-related complication occurred in 1 patient (2.9%).

Comparison between patients with easy and difficult laryngoscopy showed measurable differences in both conventional and smartphone-derived parameters. Patients with easy laryngoscopy had a mean thyromental distance of  $6.9 \pm 0.8$  cm, compared with  $5.8 \pm 0.6$  cm among patients with difficult laryngoscopy. This difference was statistically significant ( $p = 0.002$ ). The mean neck circumference was  $36.5 \pm 2.2$  cm in the easy laryngoscopy group and  $40.2 \pm 2.5$  cm in the difficult laryngoscopy group ( $p < 0.001$ ). Among smartphone-derived parameters, the mean chin projection angle was  $16.8 \pm 3.2^\circ$  in the easy laryngoscopy group and  $22.4 \pm 3.8^\circ$  in the difficult laryngoscopy group ( $p < 0.001$ ). The mean neck-chin angle was  $103.2 \pm 5.6^\circ$  among patients with easy laryngoscopy and  $113.8 \pm 6.2^\circ$  among patients with difficult laryngoscopy ( $p = 0.003$ ). After adjustment for body mass index and sex, thyromental distance remained significantly associated with difficult laryngoscopy, with an adjusted odds ratio of 0.52 per 1 cm increase, a 95% confidence interval of 0.28–0.89, and a p-value of 0.021. Chin projection angle also remained significantly associated with difficult laryngoscopy after adjustment, with an adjusted odds ratio of 1.38 per  $1^\circ$  increase, a 95% confidence interval of 1.08–1.82, and a p-value of 0.011. In the combined model adjusted for body mass index and sex, chin projection angle had an adjusted odds ratio of 1.42, with a 95% confidence interval of 1.02–1.98 and a p-value of 0.038, while thyromental distance had an adjusted odds ratio of 0.48, with a 95% confidence interval of 0.22–0.95 and a p-value of 0.042.

Sensitivity analysis showed that the association between chin projection angle and difficult laryngoscopy was stronger in males, with an adjusted odds ratio of 1.52 and a 95% confidence interval of 1.04–2.24, compared with females, in whom the adjusted odds ratio was 1.18 with a 95% confidence interval of 0.82–1.72. The interaction term was not statistically significant ( $p = 0.34$ ). Stratification by body mass index showed similar associations across normal-weight and overweight groups. Diagnostic performance analysis showed that

Mallampati Class III/IV had an apparent area under the curve of 0.72, sensitivity of 71.4%, specificity of 72.5%, positive predictive value of 33.3%, negative predictive value of 92.3%, and accuracy of 71.4% ( $p = 0.014$ ). Thyromental distance at a cut-off of less than 6.5 cm had an apparent area under the curve of 0.83 and a leave-one-out cross-validated area under the curve of 0.79, with sensitivity of 85.7%, specificity of 75.0%, positive predictive value of 42.9%, negative predictive value of 96.2%, and accuracy of 77.1% ( $p = 0.002$ ). Neck circumference at a cut-off greater than 37 cm had an apparent area under the curve of 0.78, sensitivity of 71.4%, specificity of 80.0%, positive predictive value of 50.0%, negative predictive value of 90.5%, and accuracy of 77.1% ( $p = 0.006$ ).

Among smartphone-derived measurements, chin projection angle at a cut-off greater than  $16^\circ$  had an apparent area under the curve of 0.90 and a leave-one-out cross-validated area under the curve of 0.85. It showed sensitivity of 85.7%, specificity of 85.0%, positive predictive value of 60.0%, negative predictive value of 95.2%, and accuracy of 85.7% ( $p < 0.001$ ). Neck-chin angle at a cut-off greater than  $110^\circ$  had an apparent area under the curve of 0.86 and a leave-one-out cross-validated area under the curve of 0.81, with sensitivity of 71.4%, specificity of 90.0%, positive predictive value of 66.7%, negative predictive value of 91.1%, and accuracy of 85.7% ( $p = 0.001$ ). The combined model had the highest apparent area under the curve of 0.94 and a leave-one-out cross-validated area under the curve of 0.89. It showed sensitivity of 85.7%, specificity of 90.0%, positive predictive value of 66.7%, negative predictive value of 96.6%, and accuracy of 88.6% ( $p < 0.001$ ). Internal validation of the combined model showed a reduction in performance compared with the apparent estimates. The apparent area under the curve was 0.94, while the leave-one-out cross-validated area under the curve was 0.89, with a 95% confidence interval of 0.76–0.96. The bootstrap optimism-corrected area under the curve was 0.87. Apparent accuracy was 88.6%, while leave-one-out cross-validated accuracy was 82.9% and bootstrap optimism-corrected accuracy was 80.0%. Sensitivity decreased from an apparent value of 85.7% to 71.4% after cross-validation and bootstrap correction. Specificity decreased from 90.0% to 85.7% after leave-one-out cross-validation and 82.1% after bootstrap correction. The calibration slope was 0.72, calibration-in-the-large was 0.12, and the Brier score was 0.12.

In the head-to-head model comparison, the conventional-only model, which included thyromental distance and neck circumference, had an apparent area under the curve of 0.84, a leave-one-out cross-validated area under the curve of 0.79, accuracy of 77.1%, sensitivity of 71.4%, and specificity of 78.6%. The smartphone-only model, which included chin projection angle and neck-chin angle, had an apparent area under the curve of 0.91, a leave-one-out cross-validated area under the curve of 0.86, accuracy of 85.7%, sensitivity of 71.4%, and specificity of 89.3%. The combined model, which included thyromental distance and chin projection angle, had an apparent area under the curve of 0.94, a leave-one-out cross-validated area under the curve of 0.89, accuracy of 88.6%, sensitivity of 85.7%, and specificity of 90.0%. Receiver operating characteristic analysis showed that the combined model had the highest discriminative performance, with an apparent area under the curve of 0.94, a 95% confidence interval of 0.84–0.99, and a  $p$ -value of less than 0.001. Among individual predictors, chin projection angle had an area under the curve of 0.90, followed by neck-chin angle at 0.86, thyromental distance at 0.83, neck circumference at 0.78, and Mallampati classification at 0.72. Calibration analysis of the combined model showed a calibration slope of 0.72, with a 95% confidence interval of 0.48–1.04. The calibration-in-the-large intercept was 0.12, with a 95% confidence interval of -0.38 to 0.62. The Hosmer–Lemeshow goodness-of-fit test was not statistically significant, with a chi-square value of 4.2 and a  $p$ -value of 0.38. The Brier score was 0.12.

**Table 1. Baseline Characteristics and Preoperative Airway Assessment Findings of Study Participants**

Variable	Result
<b>Total patients</b>	35
<b>Age (years), mean <math>\pm</math> SD</b>	38.7 $\pm$ 12.6
<b>Gender, n (%)</b>	
Male	22 (62.9)
Female	13 (37.1)
<b>Height (cm), mean <math>\pm</math> SD</b>	166.2 $\pm$ 8.3
<b>Weight (kg), mean <math>\pm</math> SD</b>	69.4 $\pm$ 11.7
<b>BMI (kg/m<sup>2</sup>), mean <math>\pm</math> SD</b>	25.1 $\pm$ 3.6
<b>ASA physical status, n (%)</b>	
ASA I	16 (45.7)
ASA II	17 (48.6)
ASA III	2 (5.7)

<b>Type of surgery, n (%)</b>	
General surgery	14 (40.0)
Orthopaedic surgery	10 (28.6)
ENT surgery	6 (17.1)
Urological surgery	5 (14.3)
<b>Mallampati class, n (%)</b>	
Class I	7 (20.0)
Class II	16 (45.7)
Class III	10 (28.6)
Class IV	2 (5.7)
<b>Mouth opening (cm), mean ± SD</b>	4.1 ± 0.6
<b>Thyromental distance (cm), mean ± SD</b>	6.7 ± 0.9
<b>Sternomental distance (cm), mean ± SD</b>	12.8 ± 1.6
<b>Neck circumference (cm), mean ± SD</b>	37.2 ± 2.8
<b>Upper Lip Bite Test, n (%)</b>	
Class I	15 (42.9)
Class II	16 (45.7)
Class III	4 (11.4)
<b>Neck extension, n (%)</b>	
Normal	31 (88.6)
Restricted	4 (11.4)

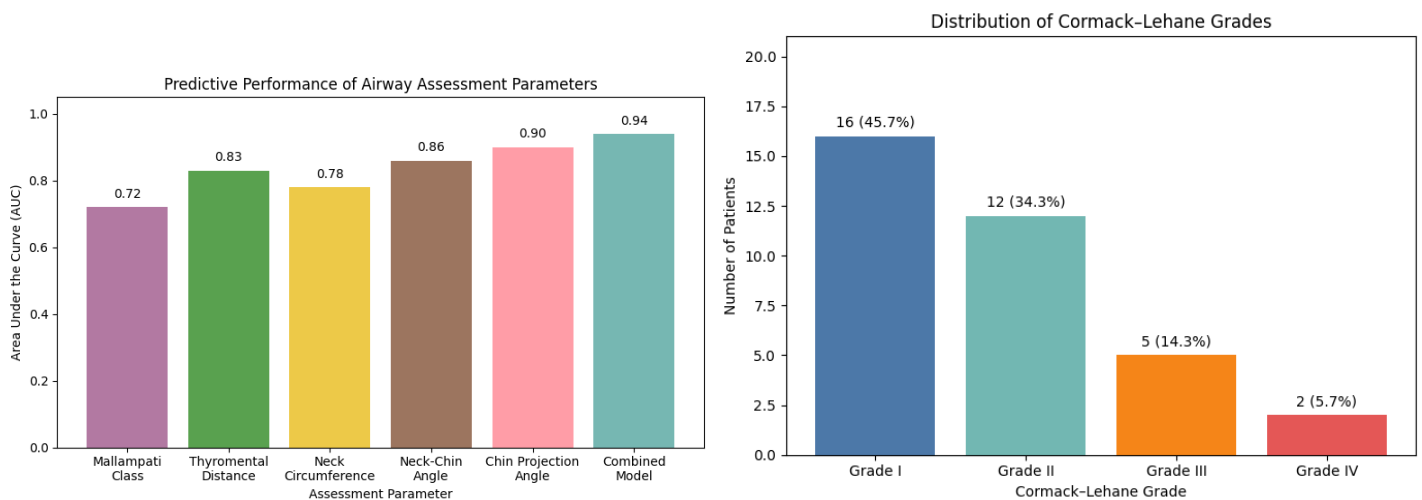
**Table 2. Smartphone-Derived Facial Anthropometric Measurements and Intraoperative Airway Outcomes**

<b>Variable</b>	<b>Result</b>
<b>Facial anthropometric measurements</b>	
Facial width (cm), mean ± SD	13.6 ± 0.9
Mandibular width (cm), mean ± SD	9.5 ± 0.7
Chin projection angle (°), mean ± SD	17.9 ± 4.2
Neck-chin angle (°), mean ± SD	105.3 ± 6.8
Neck-to-face ratio, mean ± SD	0.74 ± 0.06
Jawline angle (°), mean ± SD	128.6 ± 7.9
Reduced submandibular contour, n (%)	11 (31.4)
<b>Cormack–Lehane grade, n (%)</b>	
Grade I	16 (45.7)
Grade II	12 (34.3)
Grade III	5 (14.3)
Grade IV	2 (5.7)

Easy laryngoscopy, Grade I–II, n (%)	28 (80.0)
Difficult laryngoscopy, Grade III–IV, n (%)	7 (20.0)
Inter-rater agreement for Cormack–Lehane grading, $\kappa$	0.68
95% CI for $\kappa$	0.42–0.94
Cases improved by external laryngeal manipulation, n (%)	2 (5.7)
<b>Number of intubation attempts, n (%)</b>	
One attempt	26 (74.3)
Two attempts	6 (17.1)
Three or more attempts	3 (8.6)
Stylet used, n (%)	10 (28.6)
Bougie used, n (%)	5 (14.3)
Video laryngoscope used, n (%)	3 (8.6)
Intubation Difficulty Scale score, mean $\pm$ SD	2.8 $\pm$ 1.6
Difficult intubation, IDS >5, n (%)	4 (11.4)
Difficult mask ventilation, n (%)	1 (2.9)
Airway rescue device required, n (%)	2 (5.7)
Any airway-related complication, n (%)	1 (2.9)

**Table 3. Comparison of Key Predictors and Diagnostic Performance for Difficult Laryngoscopy**

Parameter / Model	Non-Difficult Laryngoscopy (n=28)	Difficult Laryngoscopy (n=7)	p-value	AUC	Sensitivity (%)	Specificity (%)	Accuracy (%)
Thyromental distance (cm), mean $\pm$ SD	6.9 $\pm$ 0.8	5.8 $\pm$ 0.6	0.002	0.83	85.7	75.0	77.1
Neck circumference (cm), mean $\pm$ SD	36.5 $\pm$ 2.2	40.2 $\pm$ 2.5	<0.001	0.78	71.4	80.0	77.1
Chin projection angle ( $^{\circ}$ ), mean $\pm$ SD	16.8 $\pm$ 3.2	22.4 $\pm$ 3.8	<0.001	0.90	85.7	85.0	85.7
Neck-chin angle ( $^{\circ}$ ), mean $\pm$ SD	103.2 $\pm$ 5.6	113.8 $\pm$ 6.2	0.003	0.86	71.4	90.0	85.7
Mallampati Class III/IV	—	—	0.014	0.72	71.4	72.5	71.4
Conventional-only model	—	—	—	0.84	71.4	78.6	77.1
Smartphone-only model	—	—	—	0.91	71.4	89.3	85.7
Combined model	—	—	<0.001	0.94	85.7	90.0	88.6
Combined model, LOOCV AUC	—	—	—	0.89	—	—	82.9
Combined model, optimism-corrected AUC	—	—	—	0.87	71.4	82.1	80.0



## DISCUSSION

Accurate prediction of difficult laryngoscopy before induction of anesthesia remained an important clinical concern because failure to identify high-risk patients could lead to delayed airway control, repeated intubation attempts, hypoxemia, airway trauma, and other perioperative complications. This study evaluated whether smartphone-derived facial anthropometric measurements could predict difficult laryngoscopy and compared their performance with conventional bedside airway assessment methods. The findings suggested that selected smartphone-derived measurements, particularly chin projection angle and neck-chin angle, showed better discriminatory ability than several traditional airway tests. However, the results also required cautious interpretation because the study included a small sample and a limited number of difficult laryngoscopy events. The incidence of difficult laryngoscopy in this study was 20.0%, with 7 out of 35 patients classified as Cormack–Lehane Grade III or IV. This proportion was higher than the 5–15% range commonly reported in many clinical studies. The higher frequency may have been related to the small sample size, case-mix variation, local patient characteristics, or differences in grading criteria and observer assessment. The inter-rater agreement for Cormack–Lehane grading was moderate-to-substantial, with a kappa value of 0.68, but the wide confidence interval indicated limited precision. This finding suggested that some misclassification might have occurred, particularly in borderline Grade II and Grade III views. Therefore, although the observed incidence emphasized the importance of careful airway assessment, it should not be considered a stable estimate of difficult laryngoscopy frequency in the wider surgical population.

Conventional airway assessment methods showed variable but generally moderate predictive performance. Mallampati classification demonstrated an AUC of 0.72, sensitivity of 71.4%, and specificity of 72.5%, indicating that it provided useful but incomplete predictive information. This was consistent with previous literature showing that Mallampati classification, although widely used, had limited accuracy when applied as a standalone test because it depended on patient cooperation, examiner technique, and subjective interpretation. Thyromental distance performed better, with an AUC of 0.83 and sensitivity of 85.7%, supporting the clinical relevance of reduced mandibular space in difficult laryngoscopy. Increased neck circumference was also associated with difficult laryngoscopy, which was biologically plausible because increased anterior neck soft tissue could reduce airway alignment and impair glottic visualization. A key finding of this study was the stronger predictive performance of smartphone-derived facial anthropometric measurements. Chin projection angle showed the highest individual performance, with an apparent AUC of 0.90 and a cross-validated AUC of 0.85. Neck-chin angle also demonstrated good diagnostic ability, with an apparent AUC of 0.86 and a cross-validated AUC of 0.81. Patients with difficult laryngoscopy had greater chin projection angles and larger neck-chin angles than those with easy laryngoscopy. These findings supported the view that craniofacial morphology contributed meaningfully to airway visualization and that facial measurements could capture anatomical features not fully represented by conventional bedside tests.

The observed association between facial anthropometric measurements and difficult laryngoscopy was clinically reasonable. Laryngoscopic difficulty was influenced not only by mouth opening or neck movement but also by mandibular shape, submandibular space, chin projection, facial proportions, and cervicomenal contour. Conventional bedside tests usually assessed one anatomical feature at a time, whereas facial anthropometric analysis provided a more quantitative description of the visible craniofacial profile. Previous studies had also suggested that mandibular morphology and related anatomical features were associated with difficult laryngoscopy, supporting the relevance of these measurements in airway prediction (17,18). After adjustment for sex and body mass index, both thyromental distance and chin projection angle remained significantly associated with difficult laryngoscopy. This suggested that these predictors reflected airway-related anatomical characteristics beyond generalized body habitus alone. However, the adjusted findings required conservative interpretation because only 7 difficult laryngoscopy events were available for analysis. With such a small event count, multivariable regression was vulnerable to model instability, wide confidence intervals, and overfitting. The use of Firth's bias-

reduction method helped reduce small-sample bias, but it did not fully overcome the limitations imposed by the small number of outcome events.

The comparison between conventional-only, smartphone-only, and combined models provided important information regarding the relative value of smartphone-derived measurements. The smartphone-only model achieved a higher cross-validated AUC than the conventional-only model, suggesting that smartphone-based facial assessment may offer additional predictive value. The combined model performed best, with an apparent AUC of 0.94 and cross-validated AUC of 0.89. This pattern indicated that smartphone-derived and conventional measurements may be complementary rather than interchangeable. Conventional tests such as thyromental distance remained clinically useful, while smartphone-derived measurements added objective information related to facial and mandibular morphology. The internal validation results were particularly important for interpreting the findings. The apparent AUC of the combined model decreased from 0.94 to an optimism-corrected AUC of 0.87 after bootstrap validation. This reduction suggested that the initial model performance was likely optimistic, which was expected in a small dataset. The calibration slope of 0.72 further indicated that the model produced overconfident risk estimates. In practical terms, predicted probabilities may have been too extreme, particularly in patients classified as high risk. This issue was important because poorly calibrated prediction models could influence clinical decision-making inappropriately if used without validation (19). Therefore, the combined model should be viewed as an exploratory clinical tool rather than a ready-to-use prediction model.

The findings were broadly consistent with the growing body of evidence supporting digital imaging, facial analysis, and technology-assisted airway assessment. Recent work had suggested that image-based approaches and machine-learning methods could improve airway prediction compared with traditional assessment alone, although the degree of improvement depended heavily on sample size, validation strategy, and study design (20,21). In this context, the present study contributed preliminary local evidence that smartphone-acquired facial measurements could be feasible and clinically informative in a Pakistani adult surgical population. Its value was not only in the reported diagnostic accuracy but also in demonstrating that simple, low-cost imaging could be incorporated into preoperative airway assessment. The clinical implications of these findings were relevant, particularly for resource-limited settings. Smartphone-based facial analysis was non-invasive, inexpensive, quick, and widely accessible. It required no advanced imaging equipment and could be performed during routine preoperative assessment. If validated in larger cohorts, it could help standardize airway evaluation, reduce observer-related variability, and support early identification of patients who may require advanced airway planning. Its future integration with automated image processing and artificial intelligence-based decision-support systems could further improve consistency and usability. However, such tools should support, not replace, clinical judgment and comprehensive airway evaluation (22).

The study had several strengths. It used a prospective design, applied standardized preoperative and intraoperative assessment procedures, and directly compared smartphone-derived measurements with commonly used conventional airway tests. The laryngoscopy protocol included standardized positioning, neuromuscular blockade confirmation, documentation of external laryngeal manipulation, and classification of the initial unmodified laryngoscopic view. The study also assessed inter-rater reliability in a subset of cases and performed internal validation through leave-one-out cross-validation and bootstrap resampling. These steps strengthened the methodological transparency of the study and reduced some sources of bias (23). Several limitations also needed to be acknowledged. The most important limitation was the small sample size, with only 35 participants and 7 difficult laryngoscopy events. This limited statistical power, reduced precision of diagnostic estimates, and restricted the number of predictors that could be included in multivariable models. The wide confidence intervals reflected this uncertainty. The study was also conducted at a single center, which limited generalizability to other hospitals, emergency settings, obese populations, pediatric patients, or patients with major craniofacial abnormalities (24).

Another limitation was the use of Cormack–Lehane Grade III–IV as the primary reference standard. Although this grading system was commonly used, it assessed difficult laryngoscopy rather than the full spectrum of difficult airway. Difficult airway may include difficult mask ventilation, multiple intubation attempts, failed intubation, need for rescue devices, and airway-related complications. In this study, difficult mask ventilation, difficult intubation, and rescue device use were reported, but the primary analysis centered on laryngoscopic view. Future studies should include composite airway outcomes and clinically meaningful endpoints such as intubation time, oxygen desaturation, number of attempts, failed intubation, and need for alternative airway devices (25). Measurement-related limitations were also present. Smartphone-derived facial anthropometry depended on image quality, patient positioning, lighting, camera angle, landmark identification, and measurement technique. Manual image analysis may have introduced measurement variability. The study would have been strengthened by reporting intra-rater and inter-rater reliability for each facial measurement using intraclass correlation coefficients or Bland–Altman analysis. Automated landmark detection and standardized image-processing software may improve reproducibility in future research (26).

The exclusion criteria may also have affected generalizability. Patients with facial deformities, cervical trauma, upper airway pathology, restricted mouth opening, emergency surgery, and pregnancy were excluded. Although these exclusions improved standardization and patient safety, they may have removed individuals at higher risk of airway difficulty. As a result, the model's performance in high-risk airway populations remained uncertain. Future research should evaluate smartphone-derived measurements across broader and more diverse airway risk groups (27). The comparison between smartphone-derived and conventional assessment was promising but

preliminary. The conventional-only model was limited by the small number of outcome events and could not include all potentially relevant conventional predictors. A larger study could compare comprehensive conventional models, smartphone-only models, and combined models more fairly. Formal statistical comparison of AUCs, such as paired ROC comparison, would also help determine whether the observed differences were statistically meaningful rather than due to sampling variation (28).

Overall, this study provided preliminary evidence that smartphone-derived facial anthropometric measurements may be useful adjuncts for predicting difficult laryngoscopy. Chin projection angle and neck-chin angle showed stronger predictive performance than several conventional bedside tests, and the combined model demonstrated the best overall discrimination. Nevertheless, the findings remained exploratory because of the small sample size, possible overfitting, limited calibration, and absence of external validation. Larger multicenter studies with standardized imaging protocols, automated measurement methods, robust reliability testing, and external validation are needed before smartphone-derived facial analysis can be recommended for routine clinical implementation.

## CONCLUSION

Smartphone-derived facial anthropometric measurements appeared to be a useful adjunct for predicting difficult laryngoscopy among adult surgical patients undergoing general anesthesia. In comparison with conventional bedside airway assessment methods, facial measurements—particularly those reflecting chin projection and the neck-chin profile—provided additional objective information related to airway difficulty. The findings suggested that smartphone-based facial analysis may improve preoperative airway screening by offering a simple, non-invasive, accessible, and reproducible approach that can support clinical judgment. However, the results should be interpreted as preliminary, and larger multicenter studies with standardized imaging protocols, predefined measurement cut-offs, and external validation are required before this method can be adopted in routine anesthetic practice.

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