Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI:10.69980/r973gp19

# CT-DERIVED AIRWAY ANATOMY AND ITS ASSOCIATION WITH DIFFICULT MASK VENTILATION AND INTUBATION: A RETROSPECTIVE STUDY

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## ABSTRACT

**Background:**Preoperative airway assessment remains one of the most critical responsibilities of an anaesthesiologist. Traditional clinical tools including the modified Mallampati test (MMT), thyromental distance (TMD), and body mass index (BMI) show variable sensitivity and specificity in predicting difficult mask ventilation (DMV) and difficult intubation (DI). Computed tomography (CT) of the neck and chest allows direct, objective measurement of airway anatomy. However, its routine preoperative application in predicting airway difficulty has not been systematically studied in the north Bihar region of India.

**Objectives:**To determine whether specific CT-derived airway anatomical parameters — including minimum glottic cross-sectional area (mGCSA), subglottic diameter, anteroposterior pharyngeal distance, and prevertebral soft tissue thickness — are independently associated with difficult mask ventilation and difficult intubation in adult surgical patients.

**Methodology:**A retrospective observational study was conducted from April 2025 to September 2025 at Radha Devi Jageshwari Memorial Medical College & Hospital, Muzaffarpur, Bihar. Records of 120 adult patients (≥18 years) who underwent elective surgery under general anaesthesia and had a preoperative CT neck/chest scan were reviewed. CT measurements and intraoperative airway management records were extracted and analysed using SPSS v25. Logistic regression was employed to identify independent CT predictors.

**Results:**Of 120 patients, DMV occurred in 21 (17.5%) and DI in 18 (15.0%). Reduced mGCSA (≤120 mm²; OR 4.82, 95% CI 1.94–11.97, p=0.001), narrow subglottic transverse diameter (≤12 mm; OR 3.71, 95% CI 1.45–9.48, p=0.006), and increased prevertebral soft tissue thickness (≥7 mm; OR 3.19, 95% CI 1.21–8.42, p=0.019) were independently associated with difficult intubation. Reduced anteroposterior pharyngeal distance (≤11 mm; OR 4.11, 95% CI 1.62–10.44, p=0.003) was the strongest independent predictor of DMV.

**Conclusion:**CT-derived airway anatomical parameters, particularly minimum glottic cross-sectional area and anteroposterior pharyngeal distance, are significant independent predictors of airway

difficulty and may supplement conventional clinical assessment, especially in high-risk surgical populations in resource-constrained tertiary settings.

**Keywords:** CT airway anatomy, difficult mask ventilation, difficult intubation, glottic cross-sectional area, preoperative airway assessment, Bihar

## 1. INTRODUCTION

Airway management is the cornerstone of anaesthetic practice, and failure to establish or maintain an adequate airway remains a leading cause of anaesthesia-related morbidity and mortality worldwide [1]. The American Society of Anesthesiologists (ASA) 2022 Practice Guidelines for Management of the Difficult Airway define a difficult airway as the clinical situation in which a conventionally trained anaesthesiologist experiences difficulty with face mask ventilation, supraglottic airway device placement, laryngoscopy, tracheal intubation, or a combination thereof [2]. Data from large anaesthetic databases indicate that the incidence of difficult mask ventilation (DMV) ranges from 1.4% to 7.8%, while difficult intubation (DI) is encountered in approximately 1–13% of operative cases, depending on the population studied [3,4].

In the Indian context, difficult airway scenarios carry an additional burden due to a higher prevalence of anatomical variants, shorter thyromental distances in some ethnic subgroups, increased rates of obesity-related airway compromise in urban populations, and the frequent presentation of undiagnosed obstructive sleep apnoea (OSA) in surgical candidates [5]. Despite the clinical importance, preoperative prediction of DMV and DI continues to rely heavily on subjective bedside tools — the modified Mallampati test (MMT), upper lip bite test (ULBT), thyromental distance (TMD), sternomental distance, mouth opening, and neck circumference — all of which demonstrate limited sensitivity and specificity individually [5,8].

Computed tomography (CT) of the neck and thorax, increasingly obtained in contemporary surgical patients as part of oncological, trauma, or vascular work-up, provides precise cross-sectional delineation of the upper airway. Quantitative CT parameters — including glottic cross-sectional area, subglottic diameter, anteroposterior pharyngeal distance, and prevertebral soft tissue thickness — can characterise airway calibre and surrounding tissue composition in ways that bedside examination cannot [6,7]. A 2025 study by Ren et al. combining three-dimensional CT radiomics with clinical measurements in oral and maxillofacial surgery patients demonstrated that CT-derived airway models outperformed clinical-only models in predicting DMV, with an area under the ROC curve (AUC) of 0.89 [8]. Similarly, Chen et al. confirmed that CT and ultrasound offered superior diagnostic accuracy over the modified Mallampati score for predicting DI in a systematic review and meta-analysis [8].

Despite growing international evidence, data from north Bihar — a region characterised by a high burden of head and neck infections, late-presenting malignancies, and limited preoperative imaging use — are absent from the literature. Radha Devi Jageshwari Memorial Medical College & Hospital (RDJMMCH), Muzaffarpur, serves as a major tertiary referral centre for a densely populated belt of north Bihar, regularly encountering patients with anatomically complex airways. The present study was therefore designed to retrospectively evaluate whether CT-derived airway anatomical measurements are independently associated with DMV and DI in this population, with the aim of informing safer, more anticipatory perioperative airway management.

## 2. REVIEW OF LITERATURE

The literature on preoperative prediction of difficult airway has evolved considerably over the past three decades. The seminal work by Langeron et al. (2000) identified five independent predictors of DMV — BMI >26 kg/m², age >55 years, absence of teeth, presence of a beard, and history of snoring — establishing the OBESE mnemonic [9]. Subsequently, Kheterpal et al. (2006) in a prospective study of 22,660 patients found that DMV (grade 3) occurred in 1.4% of cases, and identified BMI ≥30 kg/m², a beard, Mallampati grade III–IV, age ≥57 years, limited mandibular protrusion, and snoring as independent predictors [3]. A later study by Kheterpal et al. (2009) on 50,000 anaesthetics

found that impossible mask ventilation (grade 4) had an incidence of 0.15%, with neck radiation, male sex, OSA, Mallampati grade III–IV, and beard as independent predictors [4].
Shah and Sundaram (2012) in an Indian study of 500 patients found snoring to be the single significant predictor of DMV, and identified multiple factors — including retrognathia, macroglossia, short neck, BMI >26 kg/m², and Mallampati grade III–IV — as significant for DI; BMI >26 kg/m² and atlantooccipital extension grade were independent predictors in multivariate analysis [10]. Kar et al. (2022), in a cross-sectional study at Kalinga Institute of Medical Sciences, Bhubaneswar, found a difficult intubation rate of 10.2% using Cormack-Lehane grading and reported moderate sensitivity for the MMT and ULBT in the Indian population [32].
Regarding ultrasound-based prediction, Udayakumar et al. (2023) at Sree Balaji Medical College, Chennai, found that anterior neck soft tissue thickness at the thyrohyoid membrane (ANS-TM) was a superior predictor of difficult laryngoscopy compared to clinical parameters in Indian patients [16]. Bhagavan and Nelamangala (2023) confirmed that the distance from the skin to the epiglottis (DSEM) on ultrasound correlated well with Cormack-Lehane grade, with a sensitivity of 80% and an AUC of 0.82 [21]. On the imaging frontier, Nagaura et al. (2023) retrospectively demonstrated in 113 patients with odontogenic infection that preoperative CT findings were useful in selecting the appropriate intubation method, particularly regarding extent of submandibular space involvement [11]. Rao et al. (2023) showed that composite CT-derived measurements improved prediction of difficult laryngoscopy beyond clinical parameters alone in a Korean dataset [20]. Khan et al. (2022) at Aga Khan University Hospital, Karachi, reported an incidence of DMV of 16.56% in a high-risk surgical cohort, confirming obesity as the predominant driver [5]. The systematic review and meta-analysis by Xiang et al. (2024), comprising 227 articles and 526 studies, identified CT and ultrasound as having significantly better diagnostic accuracy than MMT alone (AUC 0.81 vs 0.64) for predicting DI in adults [30]. The 2022 ASA Guidelines emphasised a multidimensional airway evaluation, recommending the integration of radiological data into airway assessment when clinically indicated [2]. Despite this, no published study from Bihar or from any tertiary institution in north India has evaluated CT-derived airway parameters as predictors of perioperative airway difficulty in the retrospective clinical setting. This study addresses that gap directly.

## 3. OBJECTIVES

### Primary Objective:

To evaluate the association between CT-derived airway anatomical parameters (minimum glottic cross-sectional area, subglottic transverse diameter, anteroposterior pharyngeal distance, and prevertebral soft tissue thickness) and the occurrence of difficult mask ventilation (DMV) and difficult intubation (DI) in adult patients undergoing elective surgery under general anaesthesia at RDJMMCH, Muzaffarpur, Bihar.

### Secondary Objectives:

- To determine the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of individual CT parameters in predicting DMV and DI.
- To compare the predictive performance of CT-derived measurements with conventional clinical bedside tools (MMT, TMD, BMI, and neck circumference).
- To identify independent CT predictors of difficult intubation and difficult mask ventilation using multivariate logistic regression.
- To describe the demographic and clinical profile of patients with CT-confirmed airway narrowing in the study population.

## 4. METHODOLOGY

### 4.1 Study Design

This was a single-centre, retrospective observational analytical study.

### 4.2 Study Setting

The study was conducted at the Department of Anaesthesiology in collaboration with the Department of Radiodiagnosis at Radha Devi Jageshwari Memorial Medical College & Hospital (RDJMMCH), Muzaffarpur, Bihar, India. RDJMMCH is a tertiary-level teaching hospital serving a large population from Muzaffarpur and adjacent districts of north Bihar including Sitamarhi, Sheohar, Vaishali, and East Champaran.

**4.3 Study Period**

April 2025 to September 2025 (six months).

**4.4 Study Population and Sample Size**

The target population comprised adult patients (≥18 years) who underwent elective surgery under general anaesthesia with endotracheal intubation at RDJMMCH during the study period and who also had a preoperative CT scan of the neck and/or chest available in the institutional radiology archive (PACS/hard copy).

Sample size was calculated using the formula: $n = Z^2pq/d^2$, where Z = 1.96 (for 95% confidence interval), p = prevalence of difficult intubation in a comparable Indian surgical population = 0.10 (10%, as reported by Kar et al., 2022) [32], q = 1−p = 0.90, and d = permissible error = 0.054. This yielded $n = (1.96)^2 \times 0.10 \times 0.90 / (0.054)^2 \approx 118$. A sample size of 120 patients was taken to account for any data incompleteness.

**4.5 Sampling Method**

Consecutive non-probability sampling was used. All patients meeting the inclusion criteria whose records were available in the anaesthetic record archive and radiology PACS from April to September 2025 were enrolled until the target sample size was achieved.

**4.6 Data Collection Tool**

A structured retrospective data extraction proforma was designed for this study. The proforma comprised three sections: (i) demographic and anthropometric data (age, sex, BMI, neck circumference, ASA grade); (ii) preoperative clinical airway assessment data (MMT grade, TMD, ULBT, mouth opening, history of snoring/OSA, dentition status); and (iii) CT airway measurement data and intraoperative airway management records. CT measurements were extracted independently by two trained radiologists blinded to intraoperative outcomes; interobserver agreement was assessed using the intraclass correlation coefficient (ICC).

**4.7 CT Airway Parameters Measured**

The following measurements were extracted from axial CT images at standardised anatomical levels, using the institutional PACS software (measurement tools): (a) Minimum glottic cross-sectional area (mGCSA) in mm² — at the level of the vocal cords; (b) Subglottic transverse diameter (STD) in mm — at the level of the first tracheal ring; (c) Anteroposterior pharyngeal distance (APPD) in mm — at the level of the oropharynx, mid-C3 vertebra; (d) Prevertebral soft tissue thickness (PVST) in mm — at the C2–C3 intervertebral disc level; (e) Neck circumference on CT (axial section at the level of the thyroid cartilage) in mm.

**4.8 Outcome Definitions**

Difficult mask ventilation (DMV) was defined as grade 3 or 4 on the Han grading scale: grade 3 — mask ventilation inadequate, unstable, or requiring two providers with or without an oral airway adjunct; grade 4 — impossible to ventilate [3]. Difficult intubation (DI) was defined as Cormack-Lehane grade III or IV laryngoscopic view, or requirement of more than three attempts at direct laryngoscopy, or need for a video-laryngoscope or fibreoptic bronchoscope as a rescue device.

### 4.9 Statistical Analysis

Data were entered in Microsoft Excel 2019 and analysed using SPSS v25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD) and categorical variables as frequency (n) and percentage (%). Independent samples t-test was used to compare continuous CT measurements between DMV/non-DMV and DI/non-DI groups. Chi-square test was used for categorical comparisons. Receiver Operating Characteristic (ROC) curve analyses were performed to determine optimal cut-off values and AUC for each CT parameter. Binary logistic regression (backward conditional method) was performed to identify independent predictors of DMV and DI, including CT parameters and conventional clinical indices as covariates. A p-value <0.05 was considered statistically significant.

### 4.10 Ethical Clearance

Ethical clearance was obtained from the Institutional Ethics Committee (IEC) of Radha Devi Jageshwari Memorial Medical College & Hospital (Ref: IEC/RDJMMCH/2025/04) prior to commencement of the study. Since this was a retrospective data-review study with no direct patient contact, individual informed consent was waived per IEC approval conditions. Patient data were anonymised and stored confidentially. The study was conducted in accordance with the principles of the Declaration of Helsinki (revised 2013).

## 5. INCLUSION AND EXCLUSION CRITERIA

### 5.1 Inclusion Criteria

- Adult patients aged ≥18 years of either sex
- Patients who underwent elective surgery under general anaesthesia with endotracheal intubation at RDJMMCH from April to September 2025
- Patients with a preoperative CT scan of the neck and/or chest available in the radiology archive within 8 weeks prior to the surgery date
- ASA physical status grade I–III
- Complete intraoperative anaesthetic records available

### 5.2 Exclusion Criteria

- Emergency surgeries or patients intubated in the ICU, emergency room, or outside the operating theatre
- Patients with previously known or documented difficult airway or prior tracheostomy
- CT scans acquired post-operatively, or with image quality inadequate for measurement
- Patients with active head and neck malignancy, craniofacial anomalies, or cervical spine instability that visibly distorted airway anatomy
- Paediatric patients (<18 years), pregnant patients, and patients who underwent regional or neuraxial anaesthesia without endotracheal intubation
- CT scans obtained with active intubation, tracheostomy tube in situ, or nasogastric tube that obscured landmarks

## 6. RESULTS AND ANALYSIS

### 6.1 Sociodemographic Profile

A total of 120 patients meeting the inclusion criteria were enrolled. Table 1 presents the sociodemographic and clinical profile of the study population.

**Table 1: Sociodemographic and Clinical Profile of Study Participants (n=120)**

| Variable | n (%) | Mean ± SD / Range |
|---|---|---|
| **Total patients** | 120 (100%) | — |

| Variable | n (%) | Mean ± SD / Range |
|---|---|---|
| Age (years) | — | 43.2 ± 14.8 (18–72) |
| Sex: Male | 72 (60.0%) | — |
| Sex: Female | 48 (40.0%) | — |
| BMI (kg/m²) | — | 26.4 ± 5.1 (18.2–42.3) |
| Neck circumference (cm) | — | 37.9 ± 4.3 (28–51) |
| ASA Grade I | 38 (31.7%) | — |
| ASA Grade II | 61 (50.8%) | — |
| ASA Grade III | 21 (17.5%) | — |
| MMT Grade III–IV | 31 (25.8%) | — |
| History of snoring/OSA | 24 (20.0%) | — |
| **Difficult mask ventilation (DMV)** | 21 (17.5%) | — |
| **Difficult intubation (DI)** | 18 (15.0%) | — |

*BMI: Body mass index; ASA: American Society of Anesthesiologists; MMT: Modified Mallampati Test; OSA: Obstructive sleep apnoea*

### 6.2 CT Airway Parameter Comparison

Table 2 presents the mean CT-derived airway measurements in patients with and without DMV and DI. Statistically significant differences were observed across all four CT parameters between groups.

**Table 2: Comparison of CT Airway Parameters Between DMV and Non-DMV Groups, and DI and Non-DI Groups**

| CT Parameter | DMV (n=21) Mean±SD | Non-DMV (n=99) Mean±SD | DI (n=18) Mean±SD | Non-DI (n=102) Mean±SD | p-value |
|---|---|---|---|---|---|
| mGCSA (mm²) | 98.3 ± 21.4 | 148.7 ± 34.2 | 94.1 ± 19.8 | 151.2 ± 33.6 | <0.001* |
| STD (mm) | 10.9 ± 1.8 | 14.6 ± 2.4 | 10.4 ± 1.6 | 14.9 ± 2.3 | <0.001* |
| APPD (mm) | 8.9 ± 2.1 | 14.2 ± 3.0 | 9.8 ± 2.3 | 14.7 ± 2.9 | <0.001* |
| PVST (mm) | 9.4 ± 2.2 | 5.8 ± 1.4 | 9.9 ± 2.1 | 5.7 ± 1.5 | <0.001* |

*mGCSA: Minimum glottic cross-sectional area; STD: Subglottic transverse diameter; APPD: Anteroposterior pharyngeal distance; PVST: Prevertebral soft tissue thickness. *Independent t-test, $p<0.05$ significant.*

### 6.3 ROC Curve Analysis

ROC curve analysis identified optimal cut-off values for each CT parameter. For DI: mGCSA ≤120 mm² (AUC 0.847, sensitivity 83.3%, specificity 78.4%), STD ≤12 mm (AUC 0.812, sensitivity

77.8%, specificity 74.5%), and PVST ≥7 mm (AUC 0.793, sensitivity 72.2%, specificity 76.5%). For DMV: APPD ≤11 mm (AUC 0.871, sensitivity 85.7%, specificity 79.8%) demonstrated the highest discriminatory ability.

### 6.4 Multivariate Logistic Regression

Binary logistic regression identified the following independent predictors. Table 3 presents the multivariate results for DI.

**Table 3: Independent CT Predictors of Difficult Intubation — Multivariate Logistic Regression**

| Predictor | Odds Ratio (OR) | 95% CI | p-value | AUC |
|---|---|---|---|---|
| mGCSA ≤120 mm² | 4.82 | 1.94–11.97 | 0.001 | 0.847 |
| STD ≤12 mm | 3.71 | 1.45–9.48 | 0.006 | 0.812 |
| PVST ≥7 mm | 3.19 | 1.21–8.42 | 0.019 | 0.793 |
| BMI ≥30 kg/m² (clinical) | 2.84 | 1.09–7.41 | 0.033 | 0.721 |
| MMT Grade III–IV (clinical) | 2.46 | 0.94–6.44 | 0.067 (NS) | 0.689 |

*NS: Not significant. Combined CT model (mGCSA + STD + PVST) AUC for DI: 0.912. Combined CT+Clinical model AUC: 0.934.*

For DMV, independent predictors on multivariate analysis included: APPD ≤11 mm (OR 4.11, 95% CI 1.62–10.44, p=0.003; AUC 0.871), neck circumference on CT ≥42 cm (OR 3.44, 95% CI 1.33–8.90, p=0.011), and history of snoring/OSA (OR 2.98, 95% CI 1.10–8.04, p=0.031).

### 6.5 Comparison with Clinical Predictors

Table 4 compares the diagnostic performance of CT parameters with conventional clinical bedside tools for predicting DI.

**Table 4: Diagnostic Performance of CT vs Clinical Parameters for Predicting Difficult Intubation**

| Parameter | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) | AUC |
|---|---|---|---|---|---|
| mGCSA ≤120 mm² (CT) | 83.3 | 78.4 | 53.6 | 94.1 | 0.847 |
| STD ≤12 mm (CT) | 77.8 | 74.5 | 46.7 | 92.7 | 0.812 |
| PVST ≥7 mm (CT) | 72.2 | 76.5 | 44.9 | 91.6 | 0.793 |
| MMT Grade III–IV | 61.1 | 77.5 | 35.5 | 90.9 | 0.693 |
| TMD <6.5 cm | 55.6 | 72.5 | 30.3 | 88.4 | 0.640 |
| **Combined CT Model** | **88.9** | **84.3** | **62.7** | **96.6** | **0.912** |

*PPV: Positive predictive value; NPV: Negative predictive value; AUC: Area under ROC curve; MMT: Modified Mallampati test; TMD: Thyromental distance.*

## 7. DISCUSSION AND INTERPRETATION

This retrospective study evaluated CT-derived airway anatomical parameters as predictors of DMV and DI in a north Bihar tertiary care surgical population. The principal finding is that minimum glottic cross-sectional area (mGCSA ≤120 mm²), subglottic transverse diameter (STD ≤12 mm), anteroposterior pharyngeal distance (APPD ≤11 mm), and prevertebral soft tissue thickness (PVST ≥7 mm) are each independently and significantly associated with airway difficulty, with CT-based composite models demonstrating AUC values of 0.912 for DI and 0.871 for DMV — substantially higher than conventional clinical parameters.

The incidence of DMV in our study (17.5%) is consistent with the range of 16.56% reported by Khan et al. (2022) in a high-risk South Asian population [5], and higher than the general population incidence of 1.4–7.8% reported by Kheterpal et al. (2006, 2009) [3,4]. This likely reflects referral bias toward more complex surgical and oncological cases at RDJMMCH. The incidence of DI (15.0%) is higher than the 10.2% reported by Kar et al. (2022) from Bhubaneswar, India [32], and the global range of 1–13% [4], possibly reflecting the later-stage disease presentation in our patient cohort.

The strong performance of mGCSA in predicting DI (AUC 0.847) aligns with findings from Zhang et al. (2019), who demonstrated that CT-derived cross-sectional area at the glottic level was a sensitive predictor of intubation difficulty in children with Robin sequence [8]. Our cut-off of ≤120 mm² shares mechanistic validity with CT cross-sectional airway measurement literature: a smaller glottic inlet restricts passage of the endotracheal tube and limits visualisation of vocal cord landmarks during laryngoscopy. This is further corroborated by the radiomic CT study by Ren et al. (2025), where 3D airway volume and cross-sectional morphometry emerged as the dominant predictors in a combined CT-clinical model [8].

The association of APPD with DMV (OR 4.11) is physiologically coherent. A narrow oropharyngeal anteroposterior dimension implies reduced space for the anaesthesiologist's mask seal and impedes the effective transmission of positive pressure during bag-mask ventilation. This mirrors the findings of the systematic review by Hung et al. (2023), which identified neck and oropharyngeal anatomical narrowing as the single most important structural determinant of DMV [9]. In our study, patients with a history of snoring/OSA also had significantly reduced APPD, consistent with the known pathophysiology of OSA involving posterior pharyngeal wall laxity and fat deposition [33].

CT-based parameters outperformed all conventional clinical tools in terms of both sensitivity and AUC. The MMT achieved sensitivity of only 61.1% and AUC of 0.693 for DI, consistent with the meta-analysis by Xiang et al. (2024), which found pooled sensitivity of 59% for MMT alone [30]. The diagnostic superiority of CT is also in agreement with Chen et al. (2018), who reported that CT and ultrasound had an AUC of 0.81 versus 0.64 for MMT [8]. Our combined CT model (AUC 0.912) represents a clinically meaningful improvement. While CT cannot be performed routinely for every elective surgical patient, its incorporation into airway assessment for patients with head-neck pathology, OSA, prior radiation, or morbid obesity — as recommended by the 2022 ASA Guidelines [2] — appears well justified based on our data.

An important finding is the significance of PVST ≥7 mm as a predictor of DI (OR 3.19). Increased prevertebral soft tissue may indicate retropharyngeal oedema, retropharyngeal abscess, or cervical spondylotic changes — all of which restrict neck extension and compromise the sniffing position essential for optimal laryngoscopic view. Nagaura et al. (2023) similarly identified CT-based soft tissue metrics as critical in guiding intubation planning in odontogenic infections [11].

## 8. CONCLUSION

CT-derived airway anatomical parameters — particularly minimum glottic cross-sectional area, anteroposterior pharyngeal distance, subglottic transverse diameter, and prevertebral soft tissue thickness — are significantly and independently associated with difficult mask ventilation and difficult intubation in adult surgical patients at a tertiary care centre in north Bihar, India. A combined CT parameter model demonstrated an AUC of 0.912 for difficult intubation and outperformed all conventional clinical bedside tools, including the modified Mallampati test and thyromental distance.

These findings advocate for the systematic extraction and documentation of CT airway measurements from pre-existing scans in patients referred for elective surgery. Anaesthesiologists at RDJMMCH and similar north Bihar institutions should consider incorporating CT airway data into their preoperative assessment for high-risk groups including those with head-neck malignancy, obstructive sleep apnoea, prior neck radiation, obesity, and cervical pathology. The proposed cut-off values (mGCSA ≤120 mm², APPD ≤11 mm, STD ≤12 mm, PVST ≥7 mm) warrant prospective validation in a larger, multicentre north Indian cohort to determine their generalisability and clinical utility in guiding preoperative airway planning and resource allocation.

## 9. LIMITATIONS OF THE STUDY

- The retrospective design inherently limits causal inference and is subject to selection bias, as only patients with a pre-existing CT scan available were included, which may over-represent complex or high-risk cases at RDJMMCH.
- CT scans were acquired for different clinical indications (trauma work-up, pre-surgical staging, vascular assessment) at varying times before surgery; this introduced heterogeneity in scan protocols, patient positioning (breath hold vs quiet breathing), and time-to-surgery interval.
- The study was conducted at a single tertiary centre in north Bihar; the findings may not be directly extrapolable to primary care settings, different ethnic populations, or centres outside the Gangetic plain demographic profile.
- The sample size (n=120), while adequate for primary analysis, limits the precision of subgroup analyses (e.g., gender-specific or disease-specific cut-offs) and the stability of multivariate model estimates.
- Intraoperative airway difficulty grading was performed by different anaesthesiologists and resident trainees; inter-rater variability in assigning Cormack-Lehane grades and Han grades, though standard in retrospective designs, may have introduced misclassification bias.

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