EGYPTIAN JOURNAL OF ANAESTHESIA
2022, VOL. 38, NO. 1, 622–628
https://doi.org/10.1080/11101849.2022.2139107

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# Thyromental height test as a predictor of difficult airway. Single test versus multivariate predictive models. A cohort study

Mohamed Ollaek, Shady Abo Elela, Abeer Ahmed, Neamat Abdel Rahman, Gehan ElKholy, Antony Gorgy, Islam Reda and Dina Mohamed

Department of Anaesthesiology, Surgical ICU and pain management, Kasr Alainy Faculty of Medicine, Cairo University- Egypt, Cairo, Egypt

**ABSTRACT**

**Background:** Thyromental height test (TMHT) revealed good potential to predict difficult airway but with variable cut-off values. This study aimed to assess the validity of TMHT either as a sole test or within multivariable models for predicting difficult airway.
**Methods:** The study included 612 patients aged ≥18 years who were scheduled for elective surgeries under general anaesthesia with an endotracheal tube. Airway was assessed with TMHT, Thyromental distance (TMD), Sternomental distance (SMD), inter-incisor distance (IID), and Modified Mallampati test (MMT). The difficult laryngoscopy (DL) was defined as Cormack–Lehane (C-L) grade > 2. The primary outcome was the validity of TMHT as a predictor for DL.
**Results:** Cases with DL were 56 (9.2%) patients, while cases with difficult intubation (DI) were 7 (1.1%). The TMHT was significantly shorter in cases with DL compared to easy laryngoscopy (45.82 ± 8.21 versus 56.93 ± 8.83 mm, respectively) and in cases with DI compared to easy intubation (42 ± 7.19 versus 56.07 ± 9.24 mm respectively). TMHT was a good predictor for both DL and DI at a cut-off value of ≤ 48 mm with an AUROC (Area Under the Receiver Operating Characteristic) curve of 0.82 (95% CI: 0.79 to 0.85) and 0.89 (95% CI: 0.82 to 0.92), respectively. The logistic regression analysis incorporated the TMHT within two multivariable predictive models for DL and DI with better predictive ability.
**Conclusion:** In adult surgical patients, TMHT is a good objective predictor for DL and DI. The predictive ability increased when incorporated into two multivariable models.
**Trial registration:** ClinicalTrials.gov, ID: NCT04264338 in February 2020.

**ARTICLE HISTORY**
Received 21 September 2022
Revised 12 October 2022
Accepted 17 October 2022

**KEYWORDS**
Thyromental height test; thyromental distance; sternomental distance; modified mallampati; airway predictive models; difficult intubation; difficult laryngoscopy

## 1. Introduction

In anaesthetic practice, failure to secure the airway remains the most dangerous situation. Several consequences, ranging from a sore throat to cerebral damage and death, are linked to failure to maintain a patent airway after the induction of general anesthesia (GA) [1,2]. Tracheal intubation using a direct laryngoscope is still the preferred technique. The occurrence of difficult airway in literary works varies between research, ranging from 0.05 to 18% [3–5]. The incidence of the "can't intubate can't ventilate CICV" scenario during endotracheal intubation is 1:5000 straightforward GA cases, yet it is responsible for up to 25% of anaesthesia-related deaths [6].

No single anatomical landmark has been shown to predict difficult laryngoscopy (DL) reliably; however, research has shown that multifactorial indices perform marginally better than single measurements [7–9]. The thyromental height test (TMHT) was first introduced in 2013 [10]. as a good single anatomical measure for predicting the likelihood of DL. However, the studies did urge more validation trials on a broader range of patient populations due to the variability in its cut-off values [10–14].

Our study was designed to assess the validity of the TMHT as a single objective measure and as a part of multivariable models for predicting difficult airway. Our study hypothesised that the TMHT could be a good single objective predictor for difficult airways, and its predictive ability could be improved if used as a part of multivariable predictive models.

## 2. Methods

After receiving approval from the research and ethics committee of the Kasr Alainy Faculty of Medicine (ID: MD-246-2019, January 2020; email: kasralainirec@gmail.com), this observational cohort study was carried out at Cairo University Hospitals from February 2020 until February 2022. The trial was listed as NCT04264338 on ClinicalTrials.gov before patients were enrolled in it in February 2020. All patients provided their written informed consent. The study adhered to the STARD (Standards for Reporting Diagnostic Accuracy Studies).

The study included 612 patients ≥18 years with ASA physical status I and II and a body mass index (BMI) ≤ 30 kg/m$^2$ who were scheduled for elective procedures

**CONTACT** Mohamed Ollaek ollaekm@kasralainy.edu.eg Department of Anaesthesiology, Surgical ICU and Pain Management, Kasr Alainy Faculty of Medicine, Cairo University- Egypt, 1-Al Saraya st Almanial, Cairo, Egypt

under GA with the insertion of an endotracheal tube (ETT) accomplished using Macintosh laryngoscopes. We excluded patients who required awake intubation, were pregnant, had emergency surgeries, and had craniofacial, airway, or neck problems.

Age, sex, weight, height, and ASA class were noted before surgery. Two researchers who were not engaged in the induction of GA or the evaluation of the laryngoscopic view carried out the five chosen airway tests. Utilising a digital depth gauge (insize manufacturer; India) [10], the height between the thyroid cartilage's anterior border and the mentum's anterior border was measured as the ***thyromental height test (TMHT)***. During the test, the patients were supine, with their mouths closed and heads kept neutral on a 5–7 cm pillow [10,11]. While the patients were in a supine position, with their mouths closed and necks extended, the ***thyromental distance (TMD)*** was measured using a tape as a straight line between the top border of the thyroid cartilage and the bony point of the mentum [11,15]; and the ***sternomental distance (SMD)*** was measured as a straight line between the upper border of the manubrium sterni and the bony point of the mentum [15,16]. The patients were then seated with their backs supported and mouths wide open; the ***Inter-incisor distance (IID)*** was measured as the distance between the upper and lower incisors in the midline [11]. Then, the appropriate ***Modified Mallampati test (MMT)*** class was recorded [16].

In the operating theatre, non-invasive blood pressure, pulse oximetry, and an electrocardiograph were attached before induction of GA and capnography after induction of GA. Fentanyl, propofol, and atracurium were administered intravenously to induce GA after an intravenous line was inserted. 100% $O_2$ was administered for 3 minutes as preoxygenation. The mask ventilation was maintained until the peripheral nerve stimulator registered a single twitch response. The patients were kept supine in the sniffing position, which was achieved by placing a firm 7-cm cushion under the head. The laryngoscopic view was recognised, and the endotracheal intubation was performed by two of our researchers with an experience of at least ten years. Both were not informed of the outcomes of the preoperative airway testing. Using the I–IV grading scale developed by Cormack-Lehane (CL), the laryngeal view was evaluated [17]. (Grade I: a complete view of the glottis; Grade II: partial exposure of the glottis; Grade III: only the epiglottis seen; Grade IV: no view of the epiglottis). Laryngoscopy grades I and II were classified as easy, while grades III and IV were classified as difficult. For the finest laryngoscopic vision, external laryngeal manipulation was performed if necessary. Tracheal intubation that needed more than three attempts, more than ten minutes, or the use of another technique to maintain the airway was defined as difficult intubation (DI) [3]. The study's primary outcome was the validity of the TMHT as a predictor of DL. The secondary outcomes were the TMHT's reliability as a predictor of DI and its effectiveness when combined with other objective airway measurements to produce multivariable models for predicting DL and DI.

## 3. Sample size calculation

The MedCalc software was used. The sample size was calculated to determine how accurate the TMHT is in predicting DL. With a null hypothesis of an area under the receiver operating characteristic (AUROC) curve of 0.5, an AUROC curve of 0.65 was determined. A minimum of 600 patients (with at least 54 DL cases) was computed for a study power of 95%, and an alpha error of 0.05 since the incidence of DL was estimated to be 9% [10]. The number was raised to 612 to account for potential dropouts.

## 4. Statistical analysis

Statistical analysis was performed using SPSS, version 23 (Chicago, IL, USA). The Kolmogorov-Smirnov test we applied to evaluate the normality of the data distribution. Standard deviations (SD) and ranges were used to express quantitative data. The % format was used to express qualitative categorical data. The Student's t-test was used to compare normally distributed data, and the Mann-Whitney or the Kruskal-Wallis tests were used to compare non-normally distributed data. Multivariate analysis utilising logistic regression, which was also utilised to develop predictive models for DL and DI, validated the significant results. The TMHT and other tests' ability to predict DL and DI was evaluated using the AUROC curve. Therefore, patients were split into groups for easy versus difficult intubation and laryngoscopy. Calculations were made for the AUROC curve, sensitivity, specificity, and positive and negative predictive values (PPV and NPV) with the appropriate cut-off values determined Using the Youden index. Statistical significance for all tests was defined as a p-value of less than 0.05.

## 5. Results

The study included 612 (195 women and 417 men) with a mean age of 35.02 ± 11.49 years, a mean BMI of 25.85 ± 3.73 kg/m$^2$, and an ASA physical status I/II of 561/51. In addition, 56 (9.2%) patients showed DL, whereas 7 (1.1%) had DI. All cases were successfully intubated.

The demographic data and the results of the five preoperative airway tests were compared between the easy laryngoscopy group (n = 556) and the difficult laryngoscopy group (n = 56). The results demonstrated that the incidence of DL increased with ageing. In

**Table 1.** Demographic data and airway tests according to laryngoscopic view and intubation conditions.

| | Easy laryngoscopy n = 556 | Difficult laryngoscopy n = 56 | P-value | Easy intubation n = 605 | Difficult intubation n = 7 | P-value |
|---|---|---|---|---|---|---|
| Age (years) | 34.30 ± 11.27 | 42.20 ± 11.30 | < 0.001 | 34.96 ± 11.47 | 40 ± 13.05 | < 0.001 |
| Sex (male/female) | 179/377 | 16/40 | 0.69 | 192/413 | 3/4 | 0.69 |
| BMI (Kg/m$^2$) | 25.76 ± 2.96 | 26.11 ± 3.00 | 0.41 | 25.80 ± 3.01 | 27. 76 ± 1.70 | 0.09 |
| TMHT (mm) | 56.93 ± 8.83 | 45.82 ± 8.21 | < 0.001 | 56.07 ± 9.24 | 42 ± 7.19 | < 0.001 |
| TMD (cm) | 7.11 ± 1.27 | 6.39 ± 1.17 | < 0.001 | 7.05 ± 1.27 | 6.07 ± 1.93 | 0.04 |
| SMD (cm) | 14.31 ± 2.21 | 13.89 ± 2.34 | 0.18 | 14.29 ± 2.22 | 12.29 ± 0.95 | 0.02 |
| IID (cm) | 4.06 ± 0.70 | 3.71 ± 0.78 | <0.001 | 4.03 ± 0.71 | 3.50 ± 0.50 | 0.05 |
| MMT | 1 (1–2) | 3 (2–3) | <0.001 | 2 (1–2) | 3 (2–4) | < 0.001 |

Data are expressed as mean ± SD or median (IQR). BMI = body mass index, TMHT = thyromental height test, TMD = Thyromental distance, SMD = sternomental distance, IID = interincisor distance, and MMT = Modified Mallampati Test. P-value < 0.05 is statistically significant.

**Table 2.** Logistic regression analysis of Age, TMHT, TMD, SMD, IID, and MMT for predicting difficult laryngoscopy and difficult intubation.

| The test | Odds ratio | 95% CI | P-value | Odds ratio | 95% CI | P-value |
|---|---|---|---|---|---|---|
| Age | 0.05 | 0.01 | 0.008 | 1.03 | 0.96–1.11 | 0.38 |
| TMHT | 0.86 | 0.83–0.91 | < 0.001 | 0.86 | 0.78–0.95 | 0.002 |
| TMD | 0.67 | 0.46–0.98 | 0.04 | 0.62 | 0.22–1.76 | 0.37 |
| SMD | 1.18 | 0.97–1.4 | 0.09 | 0.82 | 0.51–1.32 | 0.42 |
| IID | 0.71 | 0.42–1.18 | 0.16 | 2.22 | 0.73–6.77 | 0.16 |
| MMT>2 | 5.30 | 2.57–10.95 | < 0.001 | 2.64 | 1.07–6.53 | 0.03 |

TMHT = thyromental height test, TMD = Thyromental distance, SMD = sternomental distance, IID = interincisor distance, and MMT = Modified Mallampati Test. P-value < 0.05 is statistically significant.

addition, the TMHT, TMD, and IID were much shorter, and the MMT was higher in patients with DL. (Table 1) Multivariate analysis using the logistic regression (Table 2), which corroborated the significant results, showed that age, TMHT, TMD, and MMT > 2 were independent predictors for DL. The four independent predictors were incorporated to develop a multivariate prediction model for DL (DL-Model). The DL-model predictive equation was created using the logistic regression analysis: ***The prediction (Ŷ) = 1.2+(0.04 X Age) +(−0.13 X TMHT) +(−0.6 X TMD) +(0.9 X MMT)***, provided that TMHT and TMD are expressed in centimeters. The values > 0.4 means DL while values < 0.4 (including negative values) means easy laryngoscopy. The percentage of cases correctly classified by this model was 91.5%.

Patients with DI (n = 7) and those with easy intubation (n = 605) were compared using the same criteria as before. The DI incidence increased with ageing. Among patients with DI, the TMHT, TMD, and SMD were shorter, and the MMT was significantly greater. (Table 1) Multivariate analysis utilising a logistic regression (Table 2), which supported the substantial results, showed that TMHT and MMT were the only independent predictors for DI. To develop a multivariate prediction model for DI, the MMT and TMHT were used (DI-Model) with a predictive equation: ***The prediction (Ŷ) = 2.2 +(−0.15 X TMHT) +(0.9 X MMT)***, provided that TMHT is expressed in centimeters. The values > 3.2 means DI while values < 3.2 (including negative values) means easy intubation. The percentage of cases correctly classified by this model was 98.8%.

The ROC curve was used to evaluate the validity of TMHT, TMD, SMD, IID, MMT, and DL-model to predict patients with DL (Figure 1). The Roc curve results are described in (Table 3). The TMHT provided the best prediction with an AUROC of 0.82 (95% CI = 0.79 to 0.85), a sensitivity of 71.43%, and a specificity of 85.97% at a cut-off value of ≤ 48 mm. The DL-model provided a better predictive ability with an AUROC of 0.91 (95% CI = 0.88 to 0.93), a sensitivity of 75%, and a specificity of 85% at a prediction equation value of > 0.4.

To evaluate the validity of the age, TMHT, TMD, SMD, IID, MMT, and the DI-model in predicting cases with DI, another two ROC curves were created. (Figure 2) with the curves' results described in (Table 4). The TMHT provided the best prediction with an AUROC of 0.89 (95% CI = 0.82 to 0.92), a sensitivity of 87.5%, and a specificity of 81.8% at a cut-off value of ≤48 mm. The DI-model provided a better predictive ability with an AUROC of 0.92 (95% CI = 0.90 to 0.94), a sensitivity of 100%, and a specificity of 66% at a prediction equation value of > 3.2.

## 6. Discussion

Our study found that the TMHT was a good predictor for DL and DI at a cut-off value of ≤ 48 mm. The TMHT was incorporated with age, TMD, and MMT to provide a multivariable model to predict DL and with MMT to provide another predictive model for DI. Both models provided a better predictive ability than each variable alone, with a percentage of cases correctly classified by

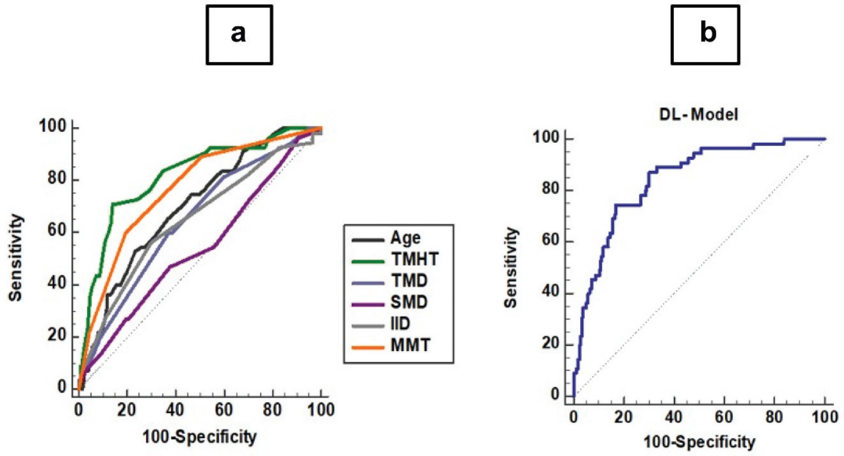


Figure 1. ROC Curves for: [A]: different airway measures and [B]: DL-model for predicting difficult laryngoscopy.

Table 3. Diagnostic accuracy of the TMHT, TMD, SMD, IID, and MMT in predicting cases with difficult laryngoscopy.

| The test | AUROC (95% CI) | Sensitivity | Specificity | PPV | NPV | Cutoff value | P-value |
|---|---|---|---|---|---|---|---|
| Age | 0.68 (0.66–0.73) | 52.7 | 76.8 | 18.4 | 94.3 | > 40 y | <0.001 |
| TMHT | 0.82 (0.79 to 0.85) | 71.43 | 85.97 | 33.9 | 96.8 | ≤ 48 mm | <0.001 |
| TMD | 0.65 (0.62 to 0.69) | 60.71 | 62.95 | 14.2 | 94.1 | ≤ 6 cm | <0.001 |
| SMD | 0.54 (0.51 to 0.58) | 48.21 | 62.23 | 11.4 | 92.3 | ≤ 13 cm | 0.292 |
| IID | 0.65 (0.61 to 0.69) | 57.14 | 69.96 | 16.1 | 94.2 | ≤ 3.5 cm | <0.001 |
| MMT | 0.76 (0.73 to 0.81) | 58.93 | 80.58 | 23.4 | 95.1 | ≥ 3 | <0.001 |
| DL-Model | 0.91 (0.88 to 0.93) | 75 | 85 | 30 | 99 | > 0.4 | 0.001 |

AUROC = area under receiver operator curve, PPV = positive predictive value, NPV = negative predictive value, TMHT = thyromental height test, TMD = thyromental distance, SMD = sternomental distance, IID = interincisor distance, MMT = Modified Mallampati Test, and DL-model = difficult laryngoscopy model. CI = confidence interval. P-value < 0.05 is statistically significant.

the DL-model reaching 91.5% and the DI-model reaching 98.8%.

In 2013, Etezadi F et al. [10] introduced the TMHT as a new airway test that evaluates the amount of mandibular protrusion, the dimensions of the submandibular area, and the anterior location of the larynx. The authors revealed promising results of the TMHT for predicting DL at a cut-off value < 50 mm, which was confirmed in 2018 in a study by Jain N et al. [12]. The sensitivity and specificity of the TMHT were evaluated in 2017 by Selvi O et al.

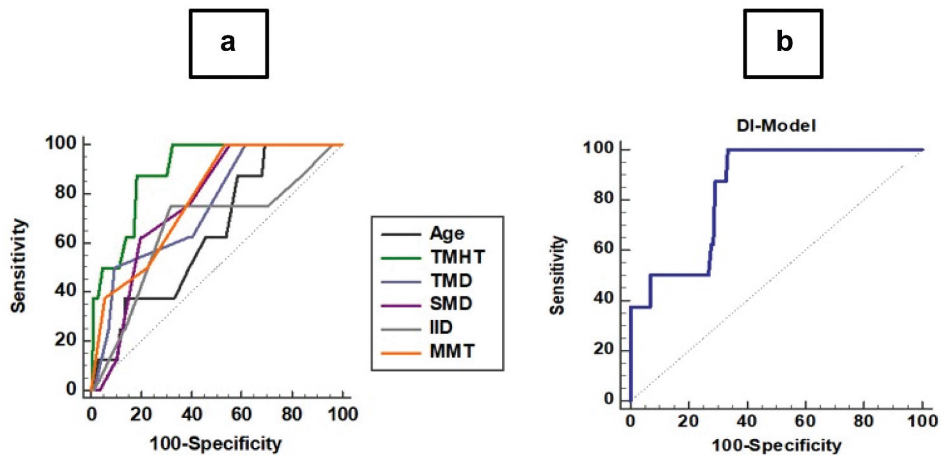


Figure 2. ROC Curves for: [A]: different airway measures and [B]: DI-model for predicting difficult intubation.

Table 4. Diagnostic accuracy of the TMHT, TMD, SMD, IID, MMT and the DI-model in predicting cases with difficult intubation.

| The test | AUROC (95% CI) | Sensitivity % | Specificity% | PPV% | NPV% | Cut-off value | P-value |
|---|---|---|---|---|---|---|---|
| Age | 0.64 (0.60 to 0.68) | 37.5 | 74.5 | 7 | 100 | >40 | 0.09 |
| TMHT | 0.89 (0.82 to 0.92) | 87.5 | 81.8 | 1.2 | 100 | ≤ 48 mm | < 0.001 |
| TMD | 0.75 (0.71 to 0.76) | 50 | 90.5 | 1.3 | 100 | ≤ 5.5 cm | 0.001 |
| SMD | 0.76 (0.73 to 0.80) | 97 | 44.3 | 1.2 | 100 | ≤ 12 cm | < 0.001 |
| IID | 0.66 (0.62 to 0.69) | 75 | 66 | 3.0 | 99.8 | ≤ 3.5 mm | 0.13 |
| MMT | 0.78 (0.75 to 0.81) | 98 | 46.45 | 2.1 | 100 | ≥3 | < 0.001 |
| DI-model | 0.92 (0.90 to 0.94) | 100 | 66 | 3.8 | 100 | >3.2 | < 0.001 |

AUROC = area under receiver operator curve, PPV = positive predictive value, NPV = negative predictive value, TMHT = thyromental height test, TMD = thyromental distance, SMD = sternomental distance, IID = interincisor distance, MMT = Modified Mallampati Test, and DI-model = difficult intubation model. CI = confidence interval. P-value < 0.05 is statistically significant.

[13] at a cut-off value of < 50 mm, yielding 91.9% and 52.2%, respectively. However, the authors provided a cut-off value of < 43.5 mm to achieve the best balance between sensitivity and specificity (64.9% and 78.02%, respectively).

The influence of the craniofacial differences, increased age, and increased BMI on the cut-off of the TMHT was proved when the test was applied to the Japanese population (≤ 54 mm) [18], geriatric population (≤ 57 mm) [19], and obese population (< 47 mm) [20] respectively. Our study's different cut-off value (≤ 48 mm) may be related to the difference in the craniofacial morphology of our studied populations, the digital method of measuring the TMHT, the use of external neck manipulation during the assessment of the laryngeal view, and the definition of the DL itself.

It was previously determined that utilising a single screening test for DL or DI has limited usefulness and that the diagnostic accuracy may be improved by employing a mix of tests to build a multivariable model [21]. SMD, TMD, IID, and MMT are objective quick bedside tests that are easy to perform with no special equipment. All proved to be good predictors for difficult airway; however, none of them alone has high diagnostic accuracy [22–25]. Zhu et al. [26] used the AUROC to categorise the test diagnostic accuracy as excellent if AUROC > 0.9, good if AUROC > 0.8, worthless if AUROC is between 0.7–0.8; and not good if AUROC is between 0.5–0.6. When predicting DL or DI in adults with apparently normal airway morphology, the tested parameter is designed to be a screening test, so the highest sensitivity is crucial in assessing the test validity [27]. Our study revealed that the best diagnostic accuracy for DL was obtained with TMHT [AUROC curve of 0.82 (95% CI: 0.79 to 0.85), a sensitivity of 71.43%]. Incorporating the TMHT into a multivariable predictive model (DL-model) improved its diagnostic accuracy [AUROC of 0.91 (95% CI: 0.88–0.93), a sensitivity of 75%]. In the case of DI, TMHT provided the best diagnostic accuracy [AUROC of 0.89 (95% CI: 0.82–0.92), a sensitivity of 87.5%]. When the TMHT was incorporated with MMT to create a multivariable predictive model for DI (DI-model), the diagnostic accuracy improved [AUROC of 0.92 (95% CI: 0.90–0.94), a sensitivity reached 100%, and NPV of 100%]. From a practical standpoint, anaesthetists are more concerned with the ability to insert an EET, so predicting DI seems more important during practice, but it should be noted that DL is the direct cause of DI in the seemingly normal airway, and the extent of the DL is a crucial predictor for DI [28].

A previous case-controlled study [9] involved 97 surgical patients; the authors examined the performance of three known multivariate predictive models (Wilson, Arne, and Naguib) in predicting unanticipated DI. The corresponding AUROC curve for the three models was 0.79, 0.87, and 0.82, while the sensitivity was 40%, 54.6%, and 81.4%, respectively. In the study mentioned above [9], the authors provided their model incorporating the height, TMD, MMT, and IID with an AUROC of 0.90 with 82.5% sensitivity and 85.6% specificity. It is important to note that while our predictive models for both DL and DI had a low positive predictive value and would wrongly label some patients as having a difficult airway, this is acceptable given the potentially fatal repercussions of an unexpectedly difficult tracheal intubation.

Our study has some limitations. For one, we only included adult patients scheduled for elective procedures, so our findings cannot be generalised to emergency or obstetric settings. Second, our study was not powered to the incidence of DI, so the results of the DI-model need to be verified by another research.

## 7. Conclusion

In adult surgical patients, TMHT is a good predictor for both DL and DI at a cut-off value of ≤ 48 mm. The predictive ability of the TMHT increased when incorporated into two new predictive models for both DL and DI.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

Support was provided solely from institutional sources.

## ORCID

Mohamed Ollaek http://orcid.org/0000-0002-0641-092X

## Author contributions

Mohamed Ollaek: This author helped with the clinical work, data collection, and writing the manuscript.
Shady Abo Elela: This author helped with the clinical work, data collection, and writing the manuscript.
Abeer Ahmed: This author helped with the conception and design of the study and writing the manuscript.
Neamat Abdel Rahman: This author helped with the clinical work and writing the manuscript.
Gehan El Kholy: This author helped with the clinical work and writing the manuscript.
Antony Gorgy: This author helped with the clinical work, data collection, and writing the manuscript.
Islam Reda: This author helped with the clinical work, data collection, and writing the manuscript.
Dina Mohamed: This author helped with the clinical work, data collection, and writing the manuscript.

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