Radiologic indicators for prediction of difficult laryngoscopy in patients with cervical spondylosis

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Conflicts of interest
None declared.

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Background: We identified the most useful variables for prediction of difficult laryngoscopy in patients with cervical spondylosis according to physical indicators and preoperative skeletal X-ray and soft tissue MRI measurements. We hypothesized that there was a closer association between difficult laryngoscopy and radiologic indicators.

Methods: We randomly enroled 315 patients undergoing elective cervical spine surgery and analysed the radiological and physical data in predicting difficult laryngoscopy.

Results: We identified five variables that were most useful in predicting difficult laryngoscopy: the inter-incisor gap ($P = 0.006$), modified Mallampati test score ($P = 0.004$), distance from the highest point of the hyoid bone to the mandibular body ($P < 0.001$), most antero-inferior point of the upper central incisor tooth ($P < 0.001$), and length of the epiglottis ($P = 0.002$). Binary multivariate logistic regression analyses identified three factors that were independently associated with difficult laryngoscopy: the Mallampati score, distance from the hyoid bone to the mandibular body, and the anterior–inferior point of the upper central incisor tooth. The odds ratios and 95% confidence intervals were 1.547 (1.029–2.327), 1.222 (1.139–1.310), and 1.224 (1.133–1.322), respectively. The AUC for hyoid bone distance to mandibular body (0.832) was larger than that of anterior-inferior point of the upper central incisor tooth (0.802, $P > 0.05$) and that of modified Mallampati test (0.602, $P < 0.05$).

Conclusion: Distance from the highest point of the hyoid bone to the mandibular body appears to be the most accurate indicator for difficult laryngoscopy in patients with cervical spondylosis.

Editorial comment
Predicting difficult laryngoscopy has remained a challenge. In this study of patients with cervical spondylosis, the radiographic indicator with best predictive value for difficult laryngoscopy was the vertical distance between the highest point of the hyoid bone and the mandibular body.

The incidence of difficult laryngoscopy and intubation ranges widely from 1.8% to 24.0% among different studies.[1–3] Patients with cervical spondylosis have a higher incidence of difficult laryngoscopy than do patients without cervical spondylosis. In such cases, the

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anaesthesiologist may encounter a large percentage of unexpected difficult airways, which are associated with increased morbidity and mortality.

Conventional predictors of difficult laryngoscopy include a high Mallampati score, small inter-incisor gap and short thyromental distance. All of these factors can be assessed using relatively quick bedside tests, but none of them alone has high diagnostic accuracy.[4] In our practice, encountering an unexpected difficult airway is not rare among patients with cervical spondylosis,[5] and the use of these physical indicators alone is not adequate for evaluation of difficult airways. Previous studies showed that X-ray examination which could provide more precise information regarding anatomical structures proved to be a suitable method for predicting a difficult airway.[6,7] However, the sample size in these studies seems small and patients are selected from many types of elective surgery. In this study, we only recruited cervical spondylosis patients (spinal cord and nerve root type), applied MRI instead of X-ray or CT to obtain better soft-tissue images and identified the most reliable variables from many indicators in predicting a difficult airway. The aim of this study was to recognize the most precise predictor for difficult laryngoscopy in patients with cervical spondylosis. Herein, we hypothesized that radiologic indicators were more closely correlated with difficult laryngoscopy compared with conventional physical indicators.

Methods

Our institutional ethics committee approved this study (IRB00006761-2015021; Medical Ethics Committee of Peking University Third Hospital, Peking University Health Science Center, Beijing) on August 26, 2013. Written informed consent was obtained from all patients during the pre-operative visit. The study was also registered at the Chinese Clinical Trial Registry (http://www.chictr.org.cn; identifier: ChiCTR-ROC-16008598) on June 6, 2016. All patients met the following inclusion criteria: Age 20–70 years, mentally competent, American Society of Anesthesiologists physical status I or II, and undergoing elective cervical spine surgery for cervical spondylosis (spinal cord and nerve root type). We excluded patients who were pregnant, experienced cervical spinal instability, or had an oropharyngeal mass.

To avoid inter-observer variability, the patients were evaluated 1 day before surgery by one anaesthesiologist who was not involved in the anaesthetic induction. Physical indicators included the inter-incisor gap (IIG), thyromental distance (TMD), and modified Mallampati test (MMT) score. The IIG (distance between the upper and lower incisors at the midline) was measured by asking each patient to open the mouth as widely as possible. The TMD (distance from the thyroid notch to the mentum) was measured with the neck fully extended and the mouth closed. The MMT score was assessed by asking each patient to open the mouth maximally while seated and protrude the tongue without phonation. The view was classified as follows: (1) good visualization of the soft palate, fauces, uvula, and pillars; (2) visualization of the soft palate, fauces, and uvula; (3) visualization of the soft palate and base of the uvula; or (4) no visualization of the soft palate.[8]

X4 was the vertical distance from the highest point of the hyoid bone to the mandibular body. Extension angle A was the angle between the line along the occlusal surfaces of the maxillary teeth and another line passing through tip of the upper incisors and antero-inferior border of the body of the sixth cervical vertebra in the extension position.

Radiological data were obtained by cervical X-ray examination and neck MRI (MR750; GE Medical Systems, Milwaukee, WI, USA). X-ray examinations were performed with the patient in the standing position, with movement of the neck only, and included both neutral and extension lateral films. All X-ray and MRI data were evaluated using the radiography information system (Centricity RIS-IC CE V3.0; GE Healthcare, Little Chalfont, UK) of Peking University Third Hospital. All distance indicators on cervical X-rays were measured in the neutral position (Fig. 1). The angle indicators on X-rays were measured on both neutral and extension lateral films (Figs 2 and 3), and the MRI indicators were measured on the lateral sagittal neck MRI film in the neutral position (Fig. 4). All imaging indicators were measured by an experienced radiologist in batches containing patients from both groups. Bias was avoided because the radiologist was blind to group allocation, and not involved in the intubation and anaesthesia management.

No premedication was allowed. Routine preoperative monitoring included non-invasive blood pressure, heart rate, pulse oximetry, and electrocardiography. Anaesthesia was induced with sufentanil (0.3 μg/kg) and propofol (2 mg/kg). When the patient lost consciousness, neuromuscular blockade was administered by injection of rocuronium (0.6 mg/kg). The difficulty of laryngoscopy was assessed with the Cormack–Lehane (C–L) scale; the result was determined during Macintosh laryngoscopy by the same senior anaesthesiologist not involved in the pre-operative radiologic assessment. The C–L scale is graded as follows: class I, vocal cords are completely visible; class II, only the arytenoids are visible; class III, only the epiglottis is visible; and class IV, the epiglottis is not visible. Patients with a class III or IV view were assigned to the difficult laryngoscopy group, and those with a class I or II view were assigned to the easy laryngoscopy group.[9] Next,

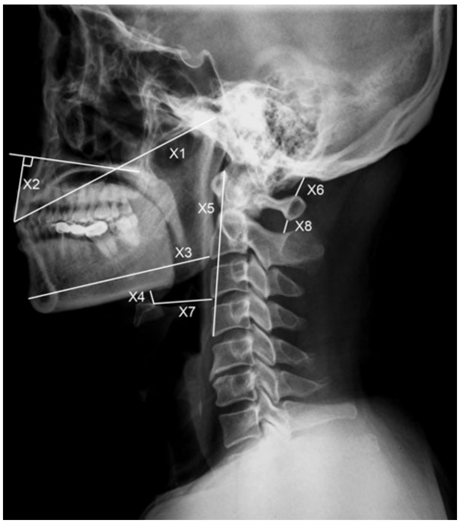

Fig. 1. Distance indicators on a lateral cervical X-ray film in the neutral position. X1, distance between the temporomandibular joint and tip of the upper incisors; X2, perpendicular distance from the hard palate to the tip of the upper incisors; X3, length of the mandibular body; X4, vertical distance from the highest point of the hyoid bone to the mandibular body; X5, distance from the antero-inferior border of the fourth cervical vertebra to the antero-superior border of the first cervical vertebra; X6, atlanto-occipital gap; X7, horizontal distance from the highest point of the hyoid bone to the border of the nearest cervical vertebra; X8, distance between the spinous processes of first cervical vertebra and the second cervical vertebra.

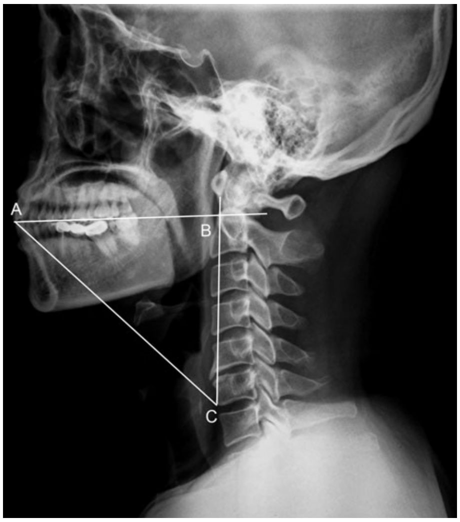

Fig. 2. Angle A, B, and C on a lateral cervical X-ray film in the neutral positions. A, tip of the upper incisors; C, antero-inferior border of the body of the sixth cervical vertebra; B, point of confluence of a line along the occlusal surfaces of the maxillary teeth and a line passing through C and the most anterior aspect of the body of the first cervical vertebra.

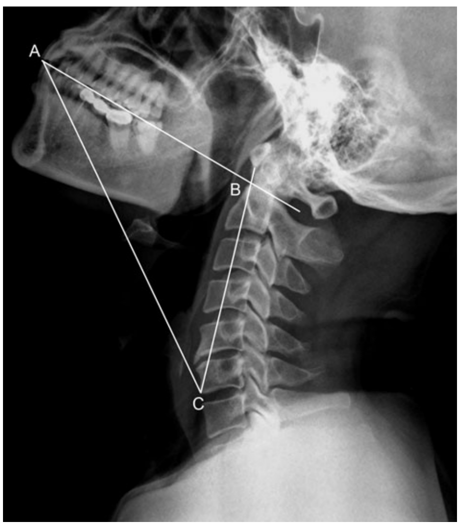

Fig. 3. Angle A, B, and C on a lateral cervical X-ray film in the extension positions. A, tip of the upper incisors; C, antero-inferior border of the body of the sixth cervical vertebra; B, point of confluence of a line along the occlusal surfaces of the maxillary teeth and a line passing through C and the most anterior aspect of the body of the first cervical vertebra.

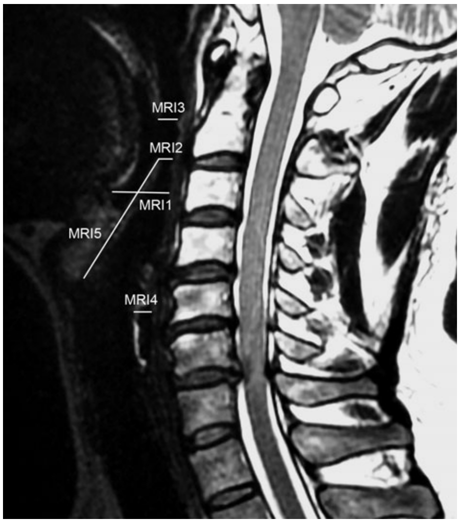

Fig. 4. Indicators on lateral sagittal neck magnetic resonance image in the neutral position. MRI1: distance between the base of the tongue and the posterior pharyngeal wall; MRI2: distance between the epiglottis and the posterior pharyngeal wall; MRI3: distance between the uvula and the posterior pharyngeal wall; MRI4: distance between the vocal cords and the posterior pharyngeal wall; MRI5: length of the epiglottis.

tracheal intubation was performed with a Macintosh laryngoscope or alternative device by the same anaesthesiologist. In patients with a difficult airway, intubation was performed according to the Difficult Airway Society 2015 guidelines.[10]

Statistics

Estimating a 24% incidence of difficult laryngoscopy,[3] a sample size of 278 patients was calculated to have a power of 0.9 and a significance level of 0.05 to detect a difference in predictors between the difficult and easy laryngoscopy groups with PASS software (version 8.03; NCSS LLC, Kaysville, UT, USA). In consideration of potential dropouts, 315 patients were recruited for the study. SPSS software (version 21.0; IBM Corp., Armonk, NY, USA) and MedCalc software (version 15.2; Ostend, Belgium) were used for the statistical analysis. Categorical variables were analysed by the χ^2 test, and continuous variables were expressed as mean ± SD with an independent-samples *t*-test. Binary multivariate logistic regression analyses were performed to identify multivariate predictors of difficult laryngoscopy. A receiver operating characteristic (ROC) curve was used to describe the discrimination abilities of the predictive indicators. The area under the curve (AUC) provides a global summary statistic of test accuracy, and guidelines suggest that $0.5 < \text{AUC} \leq 0.7$ represent low accuracy, $0.7 < \text{AUC} \leq 0.9$ moderate accuracy, and $0.9 < \text{AUC} \leq 1.0$ represents high accuracy. An AUC above 0.75 is considered as good. The 95% confidence interval (CI) was calculated, and $P < 0.05$ was considered to indicate statistical significance.

Results

We recruited 315 patients undergoing cervical spine surgery with general anaesthesia from June 2016 to December 2016 The overall incidence of difficult laryngoscopy was 17.1% (54/315).

The physical and radiologic indicators assessed in this study are listed in Table 1. Five indicators were significantly different between the easy and difficult laryngoscopy groups: the MMT score ($P = 0.004$), the IIG ($P = 0.006$), the distance from the highest point of the hyoid bone to the mandibular body (X4) ($P < 0.001$), the most antero-inferior point of the upper central incisor (extension angle A) ($P < 0.001$), and the length of the epiglottis (MRI5) ($P = 0.002$).

Using binary multivariate logistic analyses of the positive indicators, we identified three risk factors that correlated best as predictors of difficult laryngoscopy: the MMT score, X4, and extension angle A. The odds ratio and 95% CI were 1.547 (1.029–2.327), 1.222 (1.139–1.310), and 1.224 (1.133–1.322), respectively. We used the AUC to identify the predictive abilities of X4, extension angle A and the MMT score. The AUC and 95% CI for these factors were 0.832 (0.785–0.873), 0.802 (0.752–0.846) and 0.620 (0.563–0.676), respectively (Fig. 5). The AUC of X4 and extension angle A were significantly larger than that of the MMT score ($P < 0.05$), while the difference between the AUC of X4 and extension angle A was not statistically significant ($P > 0.05$).

The true-positive, true-negative, false-positive and false-negative results, together with the sensitivity, specificity, positive predictive value

Table 1 Radiologic indicators to predict difficult laryngoscopy between the two groups of patients undergoing cervical spine surgery.

Items	Easy laryngoscopy group (*n* = 261)	Difficult laryngoscopy group (*n* = 54)	*P*-values
MMT (class I II/class III IV)	171/90	24/30	0.004
IIG (cm)	4.4 ± 0.6	4.1 ± 0.5	0.006
TMD (cm)	8.2 ± 1.2	7.9 ± 1.2	0.100
X1 (mm)	115.7 ± 19.6	118.7 ± 18.3	0.305
X2 (mm)	29.8 ± 8.5	29.4 ± 6.5	0.749
X3 (mm)	87.4 ± 15.5	87.6 ± 13.3	0.919
X4 (mm)	15.6 ± 6.7	24.7 ± 7.7	< 0.001
X5 (mm)	88.9 ± 16.7	92.0 ± 13.3	0.204
X6 (mm)	6.5 ± 2.8	6.0 ± 3.2	0.181
X7 (mm)	38.2 ± 9.3	40.8 ± 10.1	0.066
X8 (mm)	5.0 ± 2.2	5.1 ± 2.2	0.713
Neutral angle A (°)	45.3 ± 4.9	46.8 ± 5.4	0.090
Extension angle A (°)	36.0 ± 5.5	42.9 ± 5.4	< 0.001
Neutral angle B (°)	88.7 ± 8.4	89.5 ± 8.2	0.511
Extension angle B (°)	96.4 ± 21.6	98.4 ± 18.2	0.536
Neutral angle C (°)	43.4 ± 4.6	42.1 ± 4.4	0.091
Extension angle C (°)	33.6 ± 5.2	34.1 ± 5.8	0.528
MRI1 (mm)	18.5 ± 7.0	18.1 ± 6.2	0.713
MRI2 (mm)	7.4 ± 3.1	7.4 ± 3.1	0.929
MRI3 (mm)	8.0 ± 3.3	7.5 ± 3.1	0.293
MRI4 (mm)	8.5 ± 2.7	8.8 ± 2.6	0.500
MRI5 (mm)	37.5 ± 8.4	41.4 ± 7.6	0.002

Values are presented as mean (standard deviation) or number (proportion). MMT, modified Mallampati test; IIG, inter-incisor gap; TMD, thyromental distance; X1, distance between the temporomandibular joint and tip of the upper incisors; X2, perpendicular distance from the hard palate to the tip of the upper incisors; X3, length of the mandibular body; X4, vertical distance from the highest point of the hyoid bone to the mandibular body; X5, distance from the antero-inferior border of the fourth cervical vertebra to the antero-superior border of the first cervical vertebra; X6, atlanto-occipital gap; X7, horizontal distance from the highest point of the hyoid bone to the border of the nearest cervical vertebra; X8, distance between the spinous processes of the first cervical vertebra and the second cervical vertebra; A, tip of the upper incisors; C, antero-inferior border of the body of the sixth cervical vertebra; B, point of confluence of a line along the occlusal surfaces of the maxillary teeth and a line passing through C and the most anterior aspect of the body of the first cervical vertebra; MRI1, distance between the base of the tongue and the posterior pharyngeal wall; MRI2, distance between the epiglottis and the posterior pharyngeal wall; MRI3, distance between the uvula and the posterior pharyngeal wall; MRI4, distance between the vocal cords and the posterior pharyngeal wall; MRI5, length of the epiglottis.

(PPV), and negative predictive value (NPV) calculated for all clinical tests, are shown in Table 2. X4 had the highest sensitivity (77.8%), specificity (71.3%), PPV (35.9%), and NPV (93.9%).

Discussion

In this study, we have shown that the incidence of difficult laryngoscopy in cervical spine surgery is 17.1%, which is higher than previously reported.[1,2] We found that the MMT score, X4 and extension angle A were three independent factors associated with difficult laryngoscopy,. The X4 factor (AUC = 0.832) was also considered to be a better indicator for patients with cervical spondylosis.

Many national airway guidelines underline the importance of a thorough and skilled airway assessment of all patients before undergoing anaesthesia.[11,12] The modified Mallampati test (MMT) is the most popular test for screening difficult laryngoscopy, but there is controversy regarding its accuracy. Lundstrom LH et al.[13] conducted a meta-analysis of 35 published studies involving 72,304 patients to evaluate the MMT as a prognostic test for difficult laryngoscopy. The pooled estimates of the sensitivity and specificity were 38% and 90%, respectively. The summary receiver operating curve demonstrated an area under the curve of 0.75. Lee A et al[14] conducted a systematic review and meta-analysis including 34,513 patients to determine the accuracy of the MMT. The summary estimate

Table 2 Evaluation of different diagnostic tests for difficult laryngoscopy in patients undergoing cervical spine surgery.

Indicators	TP	TN	FP	FN	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
MMT (III–IV)	30	171	90	24	55.6% (42.3–68.9%)	65.5% (59.7–71.3%)	25% (17.3–32.7%)	87.7% (83.1–92.3%)
IIG (≤ 4 cm)	36	157	104	18	66.7% (54.1–79.3%)	60.2% (54.3–66.1%)	25.7% (18.5–32.9%)	89.7% (85.2–94.2%)
TMD (≤ 7.5 cm)	24	171	90	30	44.4% (31.1–57.7%)	65.5% (59.7–71.3%)	21.1% (14.3–27.9%)	85.1% (79.8–90.4%)
X4 (≥ 20 mm)	42	186	75	12	77.8% (66.7–88.9%)	71.3% (65.8–76.8%)	35.9% (27.2–44.6%)	93.9% (90.6–97.2%)
Extension angle A (≥ 38°)	40	171	90	14	74.1% (62.4–85.8%)	65.5% (59.7–71.3%)	30.8% (22.9–38.7%)	92.4% (88.6–96.2%)
MRI5 (≥ 41 mm)	26	171	90	28	48.1% (34.8–61.4%)	65.5% (59.7–71.3%)	22.4% (14.8–30.0%)	85.9% (81.1–90.7%)

Values are presented as number (proportion). TP, true-positive; TN, true-negative; FP, false-positive; FN, false-negative; PPV, positive predictive value; NPV, negative predictive value; MMT, modified Mallampati test; IIG, inter-incisor gap; TMD, thyromental distance; X4, vertical distance from the highest point of the hyoid bone to the mandibular body; A, tip of the upper incisors; MRI5, length of the epiglottis.

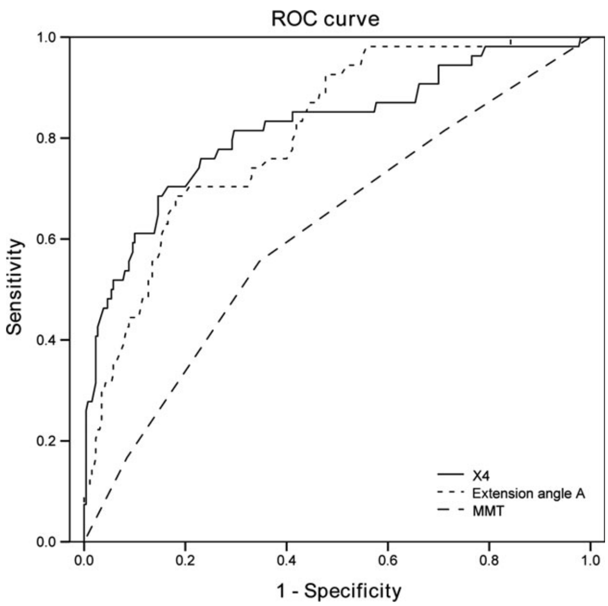

Fig. 5. X4, vertical distance from the highest point of the hyoid bone to the mandibular body; A, tip of the upper incisors; MMT, modified Mallampati test. Receiver operating characteristic curve analysis for the derivation data set. The area under the curve for the prediction of difficult laryngoscopy via X4, extension angle A and MMT ROC curve were 0.832 (95% CI = 0.785–0.873), 0.802 (95% CI = 0.752–0.846) and 0.620 (95% CI = 0.563–0.676), respectively.

for sensitivity, specificity and AUC were 55%, 84% and 0.78, respectively. In this study, the sensitive and specificity of the MMT were 55.6% and 65.5%, respectively, and the AUC was 0.620, illustrating its low predictive ability. The reason might be that the MMT, which estimates the size of the base of the tongue, reflects the volume of the oropharyngeal cavity, but cannot be used to assess the laryngeal condition. Space and mobility are two primary elements for successful direct laryngoscopy.[5] Patients undergoing surgery for cervical spondylosis have impaired cervical mobility rather than limited oropharyngeal space. This may explain why the Mallampati test, designed mostly for measurement of the oropharyngeal cavity volume, is not an effective predictor for patients undergoing cervical spine surgery.

The IIG has been demonstrated to be a useful predictor for a difficult airway in normal patients.[15] Craniocervical extension occurs during normal mouth opening, and nearly maximal mouth opening was obtained with 26° (95% CI, 22–30) of craniocervical extension from the neutral position.[16] Craniocervical extension is an integral part of complete mouth opening in conscious patients, whereas mouth opening may be restricted in patients with cervical spondylosis.[17] The TMD is also impaired by the cervical spine limitation in patients with cervical spondylosis, and a short TMD is a surrogate for inadequate head extension, rather than a small submandibular space, when indicating possible difficult direct laryngoscopy.[19] However, Khan et al.[19] found that the TMD had poor sensitivity. In this study, the AUC of IIG and TMD were 0.646 and 0.579, suggesting their unreliable predictive ability.

With developments in medical imaging, many studies have shown the relevance of radiologic indicators for difficult laryngoscopy.[20–22] Naguib et al.[23] applied radiological indicators to a predictive model of difficult airway and achieved a high sensitivity and AUC, greater than the Wilson score and Arnè model. Whether radiologic indicators have a high efficacy of predicting difficult laryngoscopy in patients with cervical spondylosis would be useful to know in the clinical setting. In this study, we examined many radiologic indicators in each patient using the C–L classification and found that X4, extension angle A and MRI5 were significantly different between the easy and difficult laryngoscopy groups ($P < 0.01$).

The X4 factor, defined as the vertical distance from the highest point of the hyoid bone to the mandibular body, was described by Naguib M[6] and Chou HC[20] in previous studies. Naguib M found that X4 demonstrated no difference between the difficult laryngoscopy group and the easy laryngoscopy group (18.3 ± 5.7 vs. 16.5 ± 5.0 mm, $P = 0.2$). However, Chou HC found that X4 was longer in the difficult laryngoscopy group than in the easy laryngoscopy group (26.4 ± 7.3 vs. 15.4 ± 6.3 mm, $P < 0.01$). In this study, we regarded X4 as an important indicator of difficult laryngoscopy (24.7 ± 7.7 vs. 15.6 ± 6.7 mm, $P < 0.001$) which was in accordance with the study reported by Chou HC. Horton et al.[24] found that the distance from the mandible to the hyoid relative to the distance from the mandible to the glottis was consistently about 50%. A long distance from the highest point of the hyoid bone to the mandibular body is associated with a deep glottis. In this condition, the anaesthesiologist has difficulty exposing the glottis because of tissue present in front of the vocal cords. According to the ROC curve in our study, the cutoff value of X4 was 20 mm. The AUC for X4 was 0.832, illustrating its good predictive accuracy.

Considering the fact that the best laryngoscopic view is achieved when the oral, pharyngeal, and laryngeal axes are closely matched, we examined the angle in different positions. Extension angle A (the most antero-inferior point of the upper central incisor tooth) was another important indicator of difficult laryngoscopy and could reflect the active degree of the cervical spine. During laryngoscopy, maximal cervical spine extension motion is expected when the patient is positioned for the best glottis view.[25] Patients with cervical spondylosis have a higher incidence of difficult laryngoscopy than patients without cervical spondylosis, and the most important reason for this might be the decreased movement of the cervical spine in the extension position. In their discriminant analysis, Naguib et al.[6] found that angle A (extension position) was a risk factor for difficult laryngoscopy and intubation. In agreement with their findings, we confirmed that angle A in the extension position was larger in the difficult than easy laryngoscopy group (42.9 ± 5.4 vs. 36.0 ± 5.5, respectively; $P < 0.001$). In the neutral position, however, no significant difference was observed between the two groups. According to the ROC curve, the cutoff value for the extension angle A was 38°. Our data indicated that extension angle A might be an alternative predictor in patients with cervical spondylosis. Nevertheless, the measurement and quantification of extension angle A was not as convenient as X4 in the screen examination.

To obtain better soft tissue images with a lower radiation hazard, we studied the role of soft tissue imaging in predicting a difficult airway using MRI rather than CT or ultrasound examination as described in previous studies.[26,27] We found that the epiglottis was significantly longer in the difficult than easy laryngoscopy group (41.4 ± 7.6 vs. 37.5 ± 8.4 mm, respectively; $P = 0.002$). When a patient undergoes laryngoscopy, the anaesthesiologist places the tip of the laryngoscope in the valley of the epiglottis and lifts the epiglottis forward and upward. If the patient has a long epiglottis, the distance from the epiglottis to the glottis decreases, hindering the view of the glottis. In other words, a long epiglottis might be more likely to cover the glottis and be associated with difficult laryngoscopy. In this study, however, the AUC of the length of the epiglottis was 0.668, suggesting its low predictive value.

The various indicators used to predict a difficult airway have different trade-offs in terms of optimizing both sensitivity and specificity. A perfect predictor should have both high sensitivity and specificity. In this study, compared with other indicators, X4 had the highest sensitivity, specificity, PPV, NPV and AUC, indicating that it plays an important role in predicting difficult laryngoscopy in patients with cervical spondylosis.

Our study had some limitations. First, determination of the best cutoff point as a predictor of difficult laryngoscopy and its analysis as a measure of prediction were both performed in the same population. This might overestimate the predictive power of the tested indicators, and an external validation would be appropriate as the next step. Second, because of the need for imaging studies, the application of radiologic indicators was limited. Fortunately, X-rays and MRI are routine pre-operative examinations in patients undergoing surgery for cervical spondylosis, and no special radiological examinations are needed to evaluate the airway. Radiologic imaging is an cost efficient screening method that makes the best use of data to predict a difficult airway without additional expense.

In conclusion, our study suggests that the vertical distance from the highest point of the hyoid bone to the mandibular body is a precise predictor in patients with cervical spondylosis and further research is warranted to verify it.

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