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Original Article

Predictors of Difficult Laryngeal Exposure in Suspension Laryngoscopy: A Systematic Review and Meta-Analysis

Mengshu Wang[1,2,3] · Yong Liu[1,2,3,4] · Yuanzheng Qiu[1,2,3,4] · Huihong Chen[1,2,3] · Wang Liwen[5]
Donghai Huang[1,2,3] · Xin Zhang[1,2,3,4] · Guo Li[1,2,3]

[1]Department of Otolaryngology Head and Neck Surgery, Xiangya Hospital, Central South University, Changsha, China
[2]Otolaryngology Major Disease Research, Key Laboratory of Hunan Province, Changsha, China
[3]Clinical Research Center for Pharyngolaryngeal Diseases and Voice Disorders in Hunan Province, Changsha, China
[4]National Clinical Research Center for Geriatric Disorders (Xiangya Hospital), Changsha, China
[5]Department of Hematology, Third Xiangya Hospital, Central South University, Changsha, China

Objectives. Considerable research has been focused on independent predictors of difficult laryngeal exposure (DLE) during suspension laryngoscopy. However, previous studies have yielded inconsistent results and conclusions. Consequently, we performed a meta-analysis of the existing literature with the aim of identifying significant parameters for a standardized preoperative DLE prediction system.

Methods. We systematically retrieved articles from the PubMed, Embase, Web of Science, China National Knowledge Infrastructure, and Wanfang databases up to October 2022. Data from eligible studies were extracted and analyzed using the R programming language. The effect measures included odds ratios (ORs) with 95% confidence intervals (CIs) for dichotomous variables and mean differences (MDs) with 95% CIs for continuous variables.

Results. The search yielded 1,574 studies, of which 18 (involving a total of 2,263 patients) were included. Pooled analysis demonstrated that patients with DLE during microsurgery tended to be male (OR, 1.73; 95% CI, 1.16–2.57); were older (MD, 5.47 years, 95% CI, 2.44–8.51 years); had a higher body mass index (BMI; MD, 1.19 kg/m^2; 95% CI, 0.33–2.05 kg/m^2); had a greater neck circumference (MD, 2.50 cm; 95% CI, 1.56–3.44 cm); exhibited limited mouth opening (MD, –0.52 cm; 95% CI, –0.88 to –0.15 cm); had limited neck flexibility (MD, –10.05 cm; 95% CI, –14.10 to –6.00 cm); displayed various other anatomical characteristics; and had a high modified Mallampati index (MMI) or test score (OR, 3.37; 95% CI, 2.07–5.48).

Conclusion. We conducted a comprehensive and systematic analysis of the factors relevant to DLE. Ultimately, we identified sex, age, BMI, neck circumference, MMI, inter-incisor gap, hyomental distance, thyromental distance, sternomental distance, and flexion-extension angle as factors highly correlated with DLE.

Keywords. *Difficult Laryngeal Exposure; Suspension Laryngoscopy; Anterior Commission; Microlaryngoscopy*

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• Corresponding author: **Guo Li**
Department of Otolaryngology Head and Neck Surgery, Xiangya Hospital, Central South University, 87 Xiangya Rd, Changsha, Hunan 410008, China
Tel: +86-731-8432-7469
Email: liguoent@csu.edu.cn

INTRODUCTION

Suspension laryngoscopy is a widely used technique in laryngeal surgery that provides surgeons with clear exposure and visualization of the larynx. This approach allows for the complete removal of laryngeal lesions, including vocal nodules, vocal cord polyps, papillomas of the larynx, and early-stage laryngeal carcinoma. Adequate exposure of the laryngeal structure, particularly the anterior commissure, is key to the success of microlaryngeal surgery.

To date, no universally accepted definition or grading system is available for difficult laryngeal exposure (DLE). Non-DLE has been described as allowing a full view of the anterior commissure with a standard adult laryngoscope [1], while cases in which only the posterior commissure or epiglottis is visible have been classified as DLE [2]. The debate surrounding the definition of DLE centers on two issues: first, whether visualization of the anterior commissure necessitates the application of external laryngeal counterpressure [3,4]; and second, whether limitations in vocal cord exposure should be defined at the first third or the last third of the cords [5-7]. Despite varying definitions, researchers have endeavored to identify factors that can predict DLE. Current evidence highlights the roles of numerous parameters in predicting DLE in clinical practice, yet previous studies have reported inconsistent results and conclusions. Hsiung et al. [8] reported that an increased body mass index (BMI) does not predict DLE, while Pinar et al. [2] observed a statistically significant difference in BMI between patients with and without DLE. Variations in patient posture also impact anthropometric measurements, such as those taken in the neutral position compared to under full neck extension [2,8]. Therefore, a thorough evaluation of diverse patient parameters is required for precisely identifying DLE, which is essential for satisfactory surgical outcomes.

MATERIALS AND METHODS

Following the preferred reporting items for systematic reviews and meta-analysis guidelines [9], we performed a meta-analysis of studies that comprehensively compared the parameters between patients with and without DLE. The methodology followed the principles of the Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy.

Eligibility criteria

According to the population, intervention, comparison, outcomes, and study design framework, the inclusion criteria were as follows: (1) patients undergoing suspension laryngoscopy owing to benign or malignant laryngeal lesions; (2) no comparison intervention; (3) comparison of patients with DLE with those without DLE in various parameters including age, BMI, sex, physical examination data and so on; and (4) secure records and ascertainment of laryngeal exposure situation as the outcome. (5) Prospective or retrospective case-control studies. The exclusion criteria were as follows: (1) review articles, case reports, case series, letters, editorials, comments, and conferences; (2) lack of explicit DLE definition; and (3) insufficient patient information and raw data.

Information sources and search strategy

A systematic electronic literature search was performed on common databases, including PubMed, Embase, Web of Science, China national knowledge infrastructure (CNKI), and Wanfang, until October 2022. To improve the sensitivity of the search strategy, we used the terms "suspension laryngoscopy," "microsurgery," "microlaryngoscopy," "microscopic," "laryngeal exposure," "difficult laryngoscopy," "predict," and "factor" as either keywords or MeSH terms. The search strategies were modified for each database as presented in Supplementary Table 1. Bibliographies of the retrieved studies were manually checked for additional eligible studies. Only published studies were included in the present meta-analysis.

Selection and collection process

Two reviewers independently screened the retrieved records; based on the inclusion and exclusion criteria, eligibility of the studies was decided. In case of any conflict, the decision of the senior authors was accepted. Data compatible with the outcome and detailed information about the experimental design of each study were manually extracted from the included studies by a reviewer and checked by another. The extracted data were divided into three parts: (1) literature information including the first author, publication date, sample size, and publication journal; (2) study methodology: research type, statistical method, the definition of DLE, representativeness of the cases, ascertainment of DLE and non-DLE groups; (3) investigated parameters: general parameters including age, sex, BMI, and physical examination parameters including neck circumference (NC), neck flexion-extension angle/atlanto-occipital extension, inter-incisor gap (IIG), hyoid-mental distance (HMD), thyroid-mental distance (TMD), sternomental distance (SMD), vertical thyroid-mental distance (VTMD), horizontal thyroid-mental distance (HTMD), thyroid-mental angle (TMA), modified Mallampati index or test (MMI/MMT) [10], and modified Cormack-Lehane scoring (MCLS) [11]. Details are listed in Supplementary Tables 2 and 3.

Assessment

Utilizing the Newcastle-Ottawa Scale (NOS) [12], two reviewers screened and scored all potential studies. For case-control studies, the star system was used to perform a semi-quantitative assessment of study quality, in which studies with six or more

HIGHLIGHTS

- This study involved an investigation of critical predictors of difficult laryngeal exposure in suspension laryngoscopy.
- We carefully retrieved and screened over 1,000 studies from various databases and registers.
- The study protocol strictly adhered to guidelines for meta-analyses, with a well-described methodology.

stars were defined as high quality with less selection, performance, detection, and attrition bias. According to the number and features of the included studies, publication bias was evaluated using Egger's and Begg's tests. These analyses are presented in Supplementary Table 4.

Statistical analysis

Review Manager 5.4 (Nordic Cochrane Center, Cochrane Collaboration) and R language (R version 4.0.2, meta24, and forest plot 25 package) were used as recommended software for meta-analysis. The different effect measures used in the presentation of results to evaluate the analysis outcome were as follows: odds ratios (ORs) with 95% confidence intervals (CIs) for dichotomous variables, and mean difference (MD) with 95% CIs for continuous variables. The synthesis of results was performed by two reviewers depending on the characteristics of the enrolled parameters in each study. Missing summary statistics were eliminated, and data conversion was used for better synthesis, such as the transition between data of the fully open mouth and inter incisor gap. According to the respective DLE definition, we divided studies into 4 categories as A, B, C, and D for subgroup analysis to control the bias due to different methods of ascertainment for laryngeal exposure. The extent of statistical heterogeneity was evaluated using the chi-square test and I^2 test within and between subgroups resulting in the different models used, the random effect model for high heterogeneity ($P<1$, $I^2>50\%$) and fixed-effect model for the contrary [13]. The leave-one-out method was used for sensitivity analysis and the publish bias was evaluated by Egger's and Begg's test. Details of subgroups are listed in Supplementary Table 5.

RESULTS

Study selection

A total of 1,574 articles were retrieved using the designed research strategies: 270 from PubMed, 522 from Web of Science, 356 from Embase, 256 from CNKI, and 170 from Wanfang. After the removal of 400 duplicates, the remaining 1,174 articles were initially screened based on reference type, title, keywords, and abstract. Fifty-two studies with available full texts underwent qualitative and quantitative evaluation, of which 19 studies defined DLE identically or similarly. One study was excluded due to data duplication with another included study. After a comprehensive evaluation, 18 studies that reported the mean value and standard deviation of each parameter in DLE and non-DLE groups were included. A flow diagram detailing the literature retrieval, screening, and synthesis process is presented in Fig. 1.

Study characteristics

In the 18 included studies, a total of 704 patients were classified as having DLE, while 1,559 were in the non-DLE category. These patients hailed from various countries, including China, India [1], Tunisia [14], and Turkey [2], and all underwent microlaryngosurgery. The most frequently reported parameters across

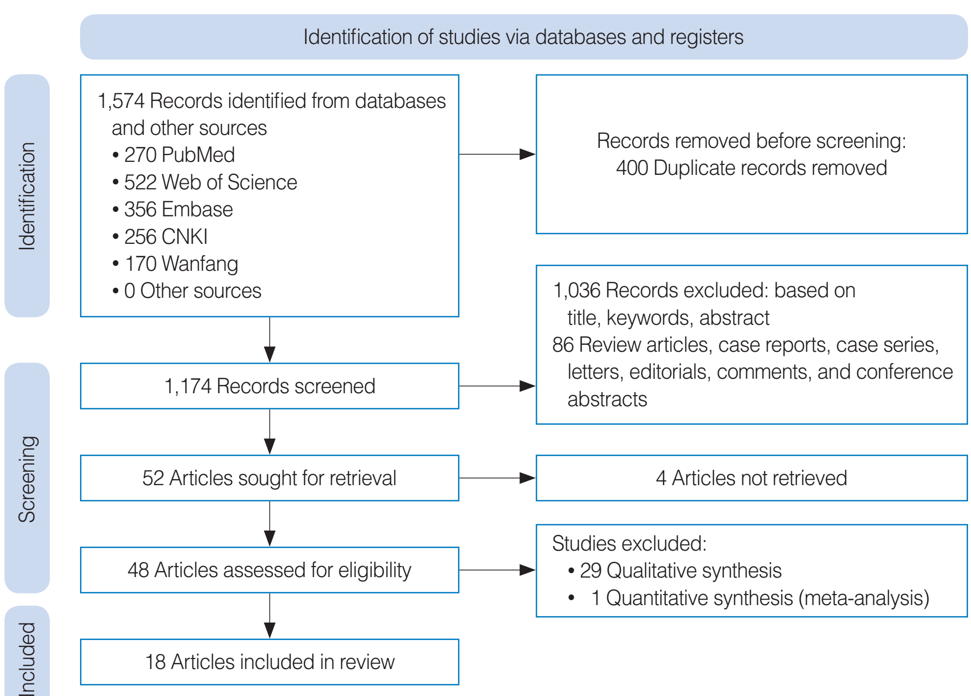


Fig. 1. Flow diagram of article screening for systematic review. CNKI, China National Knowledge Infrastructure.

Table 1. Characteristics of the 18 included studies

First author (year)	Type of analysis	Number of parameters	Number of patients with DLE	Number of patients without DLE	NOS stars
Meng (2010) [15]	Prospective	10	7	46	7
Wang (2012) [16]	Prospective	11	20	69	7
Sun (2015) [17]	Prospective	9	64	93	7
Wang (2015) [18]	Prospective	8	81	206	7
Huang (2016) [19]	Prospective	12	6	52	7
Wa (2016) [20]	Prospective	18	22	40	7
Paul (2016) [1]	Prospective	11	31	86	7
Jin (2016) [21]	Prospective	10	35	158	7
Li (2017) [22]	Prospective	14	35	55	7
Pinar (2009) [2]	Prospective	11	22	71	7
Liu (2021) [23]	Prospective	11	52	98	7
Liu (2022) [24]	Prospective	7	22	73	7
Chen (2019) [25]	Retrospective	11	63	121	6
Cheng (2020) [26]	Prospective	13	97	113	7
Hsiung (2004) [8]	Prospective	9	19	37	6
Wei (2018) [27]	Prospective	7	32	46	7
Wang (2021) [28]	Prospective	12	37	141	6
Kharrat (2022) [14]	Prospective	16	19	62	7

DLE, difficult laryngeal exposure; NOS, Newcastle-Ottawa Scale.

these studies were age, sex, and BMI, in that order. The physical examination parameters pooled from each study included NC, neck flexion-extension angle, IIG, HMD, TMD, SMD, VTMD, HTMD, TMA, MMI, and MCLS. These anatomical parameters are illustrated in Supplementary Fig. 1. All studies achieved a rating of at least six stars on the NOS, with most showing broad consistency across three domains: participant selection, comparability of study groups, and outcome ascertainment. The characteristics of the included studies are summarized in Table 1 [1,2,8,14-28] and Supplementary Table 3.

Results of syntheses

The evidence suggests that DLE was more likely to occur in male participants (OR, 1.73; 95% CI, 1.16–2.57; $I^2=65\%$; $P=0.007$). Of 12 studies, which included 822 male and 806 female participants, all but three found a significant sex difference. Seven studies reported on the age distribution among patients, comprising 310 individuals with DLE and 537 without it. Due to study heterogeneity ($P=0.003$, $I^2=70\%$), a random-effects model was employed for the analysis. The pooled data indicated that patients with DLE tended to be older than those without DLE (MD, 5.47 years; 95% CI, 2.44–8.51 years; $P=0.0004$). BMI was another general parameter found to be associated with laryngeal exposure. We analyzed all available BMI data from eight studies using a random-effects model ($P<0.0001$, $I^2=78\%$). A significant difference in BMI was noted between the two groups (MD, 1.19 kg/m^2; 95% CI, 0.33–2.05 kg/m^2; $P=0.007$). General information regarding these parameters is depicted in Fig. 2.

A pooled meta-analysis revealed that the DLE group exhibited a significantly larger NC than the non-DLE group (MD, 2.50 cm; 95% CI, 1.56–3.44 cm; $I^2=73\%$; $P<0.00001$), a finding consistent across all subgroup analyses. The DLE group also had a significantly shorter IIG compared to the non-DLE group (MD, –0.52 cm; 95% CI, –0.88 to –0.15 cm; $I^2=95\%$; $P=0.005$) in six studies, although the pooled results of two studies [23,25] showed no significant difference in the subgroup analysis. Five studies addressed the flexion-extension angle, revealing a notably smaller angle in patients with DLE (MD, –10.05 cm; 95% CI, –14.10 to –6.00 cm; $I^2=90\%$; $P<0.00001$) compared to those without DLE. For HMD, the difference was assessed in both neutral (MD, –0.23 cm; 95% CI, –0.35 to –0.12 cm; $P<0.0001$) and full extension positions (MD, –0.46 cm; 95% CI, –0.70 to –0.22 cm; $P=0.0002$). The heterogeneity of HMD in the neutral position ($I^2=0\%$, $P=0.74$) was significantly lower than in full extension ($I^2=83\%$, $P<0.0001$); this pattern was also observed for heterogeneity between and within subgroups. Similarly, TMD measurements in both the neutral position (MD, –0.54 cm; 95% CI, –0.91 to –0.17; $I^2=87\%$; $P=0.004$) and the full extension position (MD, –1.09 cm; 95% CI, –1.32 to –0.86; $I^2=68\%$; $P<0.00001$) were shorter in the DLE group, according to seven studies. Four studies also measured the horizontal and vertical components of TMD in both positions, but they revealed no statistical differences in these four parameters. SMD differed significantly in only the full extension position (MD, –1.85 cm; 95% CI, –2.05 to –1.65; $I^2=47\%$; $P<0.00001$), with no significant difference in the neutral position (MD, –0.23 cm; 95% CI, –0.46 to 0.01; $I^2=0\%$; $P=0.06$). Figs. 3 and 4 detail the synthesized results regarding anatomical characteristics.

Several indices have been investigated as potential predictors

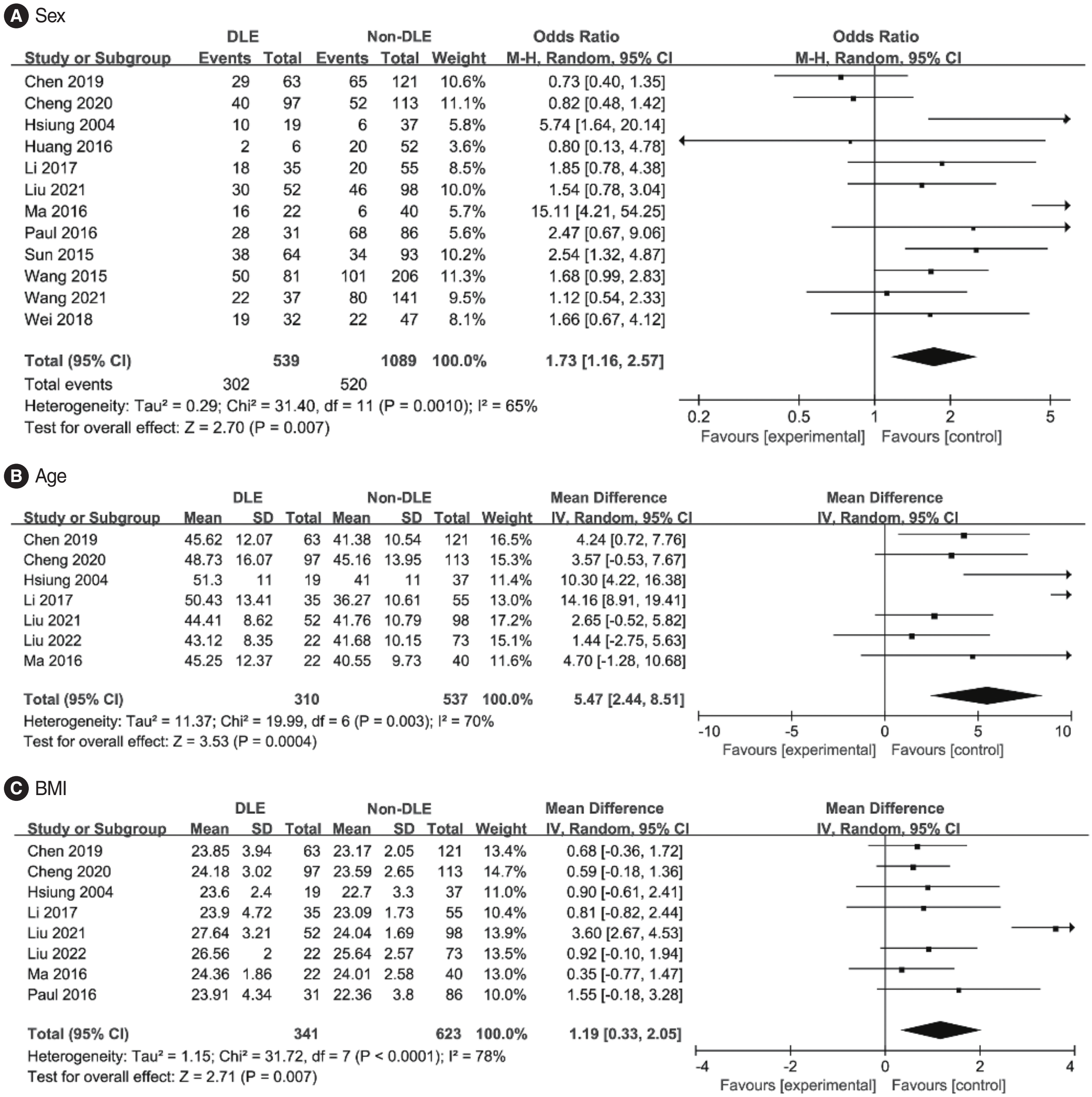


Fig. 2. Forest plots illustrating the differences in general parameters, including sex (A), age (B), and body mass index (BMI; C) between the difficult laryngeal exposure (DLE) and non-DLE groups. M-H, Mantel–Haenszel; CI, confidence interval; SD, standard deviation; IV, inverse variance.

of DLE or difficult intubation, including visual analog score, Mallampati index, MMI/MMT, MCLS, and Yamamoto index. Our analysis focused on the two most common indices, MMI and MCLS. Based on data from 12 studies, we observed a higher risk of a poor MMI index in patients with DLE compared to those without it (OR, 3.37; 95% CI, 2.07–5.48; I^2=70%; P< 0.0001). In contrast, the aggregated results for MCLS showed no significant differences. The results of MMI are shown in Fig.5. Subgroup analyses revealed that studies with varying definitions of DLE sometimes reached different conclusions; however, these differences were not statistically significant, as the tests for subgroup differences were negative (all P>0.05). The sensitivity analysis and assessment of publication bias are summarized in Supplementary Table 5. Both Egger and Begg tests suggested an absence of significant publication bias in the included studies (all P>0.05). The results for all parameters that showed statisti-

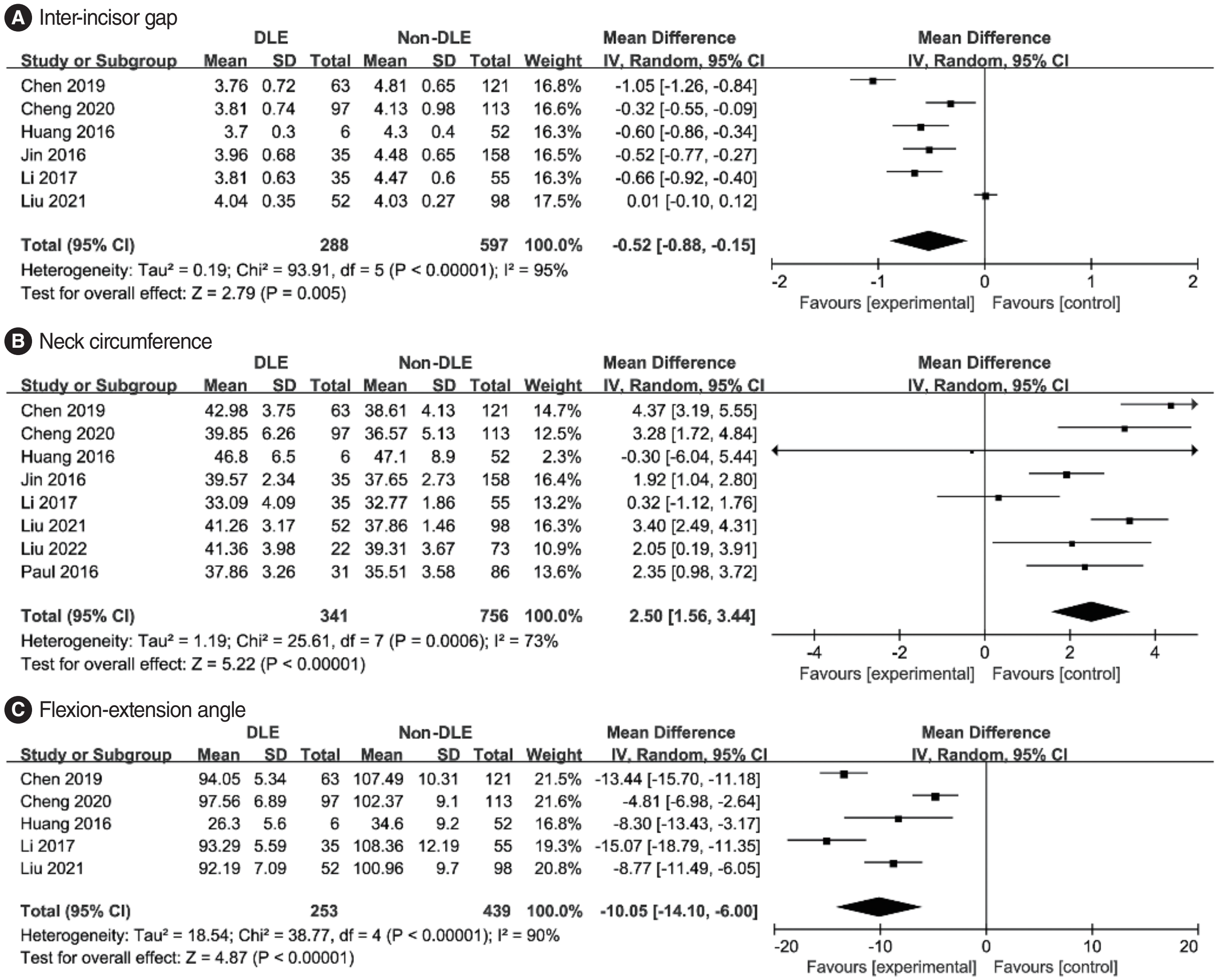


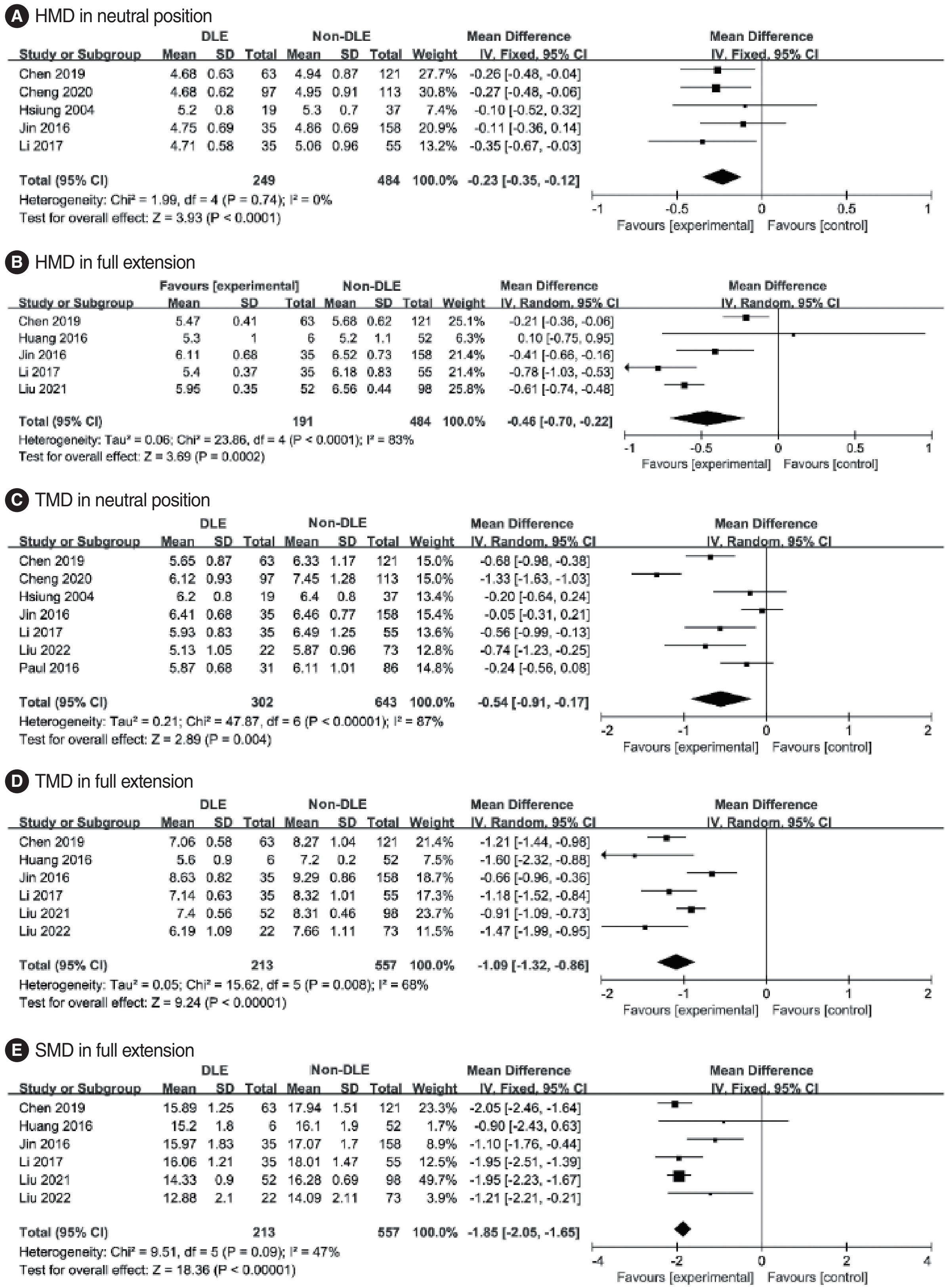
Fig. 3. Forest plots illustrating the differences in anatomical characteristics including inter-incisor gap (A), neck circumference (B), and flexion-extension angle (C) between the difficult laryngeal exposure (DLE) and non-DLE groups. SD, standard deviation; IV, inverse variance; CI, confidence interval.

cally significant results were validated using the leave-one-out method.

DISCUSSION

In this study, a thorough and focused meta-analysis of prospective controlled studies was conducted to identify key predictive factors for DLE during suspension laryngoscopy. We examined laryngeal exposure and associated patient parameters, ultimately identifying 12 independent predictors of DLE. These included sex, age, BMI, MMI, NC, IIG, neck flexion-extension angle, HMD in neutral position, HMD in full extension, TMD in neutral position, TMD in full extension and SMD in full extension. The synthesized findings suggested that achieving complete and clear laryngeal exposure during microsurgery is more challenging in patients who are older, have a higher BMI, exhibit a bull-necked appearance (greater NC), possess limited mouth opening and neck joint mobility, display relatively short anatomical distances, and exhibit higher MMI.

Of the general parameters, sex, BMI, and age displayed statistical significance in this meta-analysis, aligning with findings from previous studies. Clinical observations have indicated that relative to women, men exhibit higher rates of characteristics such as a short, thick, stiff, and muscular neck; obesity; macroglossia; and limited cervical spine extension [29-31]. High levels of adiposity may impair muscle activation, leading to functional limitations. Hekiert et al. [5] suggested that individuals with obesity were about 6.5 times more likely to experience DLE than those without obesity. Obesity-related DLE has been consistently associated with decreased oxygen saturation, limited jaw mobility, narrow upper airway, and increased muscle size



A HMD in neutral position

Study or Subgroup	DLE Mean	DLE SD	DLE Total	Non-DLE Mean	Non-DLE SD	Non-DLE Total	Weight	Mean Difference IV, Fixed, 95% CI
Chen 2019	4.68	0.63	63	4.94	0.87	121	27.7%	-0.26 [-0.48, -0.04]
Cheng 2020	4.68	0.62	97	4.95	0.91	113	30.8%	-0.27 [-0.48, -0.06]
Hsiung 2004	5.2	0.8	19	5.3	0.7	37	7.4%	-0.10 [-0.52, 0.32]
Jin 2016	4.75	0.69	35	4.86	0.69	158	20.9%	-0.11 [-0.36, 0.14]
Li 2017	4.71	0.58	35	5.06	0.96	55	13.2%	-0.35 [-0.67, -0.03]
Total (95% CI)			**249**			**484**	**100.0%**	**-0.23 [-0.35, -0.12]**

Heterogeneity: Chi² = 1.99, df = 4 (P = 0.74); I² = 0%
Test for overall effect: Z = 3.93 (P < 0.0001)

B HMD in full extension

Study or Subgroup	Favours [experimental] Mean	SD	Total	Non-DLE Mean	Non-DLE SD	Non-DLE Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2019	5.47	0.41	63	5.68	0.62	121	25.1%	-0.21 [-0.36, -0.06]
Huang 2016	5.3	1	6	5.2	1.1	52	6.3%	0.10 [-0.75, 0.95]
Jin 2016	6.11	0.68	35	6.52	0.73	158	21.4%	-0.41 [-0.66, -0.16]
Li 2017	5.4	0.37	35	6.18	0.83	55	21.4%	-0.78 [-1.03, -0.53]
Liu 2021	5.95	0.35	52	6.56	0.44	98	25.8%	-0.61 [-0.74, -0.48]
Total (95% CI)			**191**			**484**	**100.0%**	**-0.46 [-0.70, -0.22]**

Heterogeneity: Tau² = 0.06; Chi² = 23.86, df = 4 (P < 0.0001); I² = 83%
Test for overall effect: Z = 3.69 (P = 0.0002)

C TMD in neutral position

Study or Subgroup	DLE Mean	DLE SD	DLE Total	Non-DLE Mean	Non-DLE SD	Non-DLE Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2019	5.65	0.87	63	6.33	1.17	121	15.0%	-0.68 [-0.98, -0.38]
Cheng 2020	6.12	0.93	97	7.45	1.28	113	15.0%	-1.33 [-1.63, -1.03]
Hsiung 2004	6.2	0.8	19	6.4	0.8	37	13.4%	-0.20 [-0.64, 0.24]
Jin 2016	6.41	0.68	35	6.46	0.77	158	15.4%	-0.05 [-0.31, 0.21]
Li 2017	5.93	0.83	35	6.49	1.25	55	13.6%	-0.56 [-0.99, -0.13]
Liu 2022	5.13	1.05	22	5.87	0.96	73	12.8%	-0.74 [-1.23, -0.25]
Paul 2016	5.87	0.68	31	6.11	1.01	86	14.8%	-0.24 [-0.56, 0.08]
Total (95% CI)			**302**			**643**	**100.0%**	**-0.54 [-0.91, -0.17]**

Heterogeneity: Tau² = 0.21; Chi² = 47.87, df = 6 (P < 0.00001); I² = 87%
Test for overall effect: Z = 2.89 (P = 0.004)

D TMD in full extension

Study or Subgroup	DLE Mean	DLE SD	DLE Total	Non-DLE Mean	Non-DLE SD	Non-DLE Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2019	7.06	0.58	63	8.27	1.04	121	21.4%	-1.21 [-1.44, -0.98]
Huang 2016	5.6	0.9	6	7.2	0.2	52	7.5%	-1.60 [-2.32, -0.88]
Jin 2016	8.63	0.82	35	9.29	0.86	158	18.7%	-0.66 [-0.96, -0.36]
Li 2017	7.14	0.63	35	8.32	1.01	55	17.3%	-1.18 [-1.52, -0.84]
Liu 2021	7.4	0.56	52	8.31	0.46	98	23.7%	-0.91 [-1.09, -0.73]
Liu 2022	6.19	1.09	22	7.66	1.11	73	11.5%	-1.47 [-1.99, -0.95]
Total (95% CI)			**213**			**557**	**100.0%**	**-1.09 [-1.32, -0.86]**

Heterogeneity: Tau² = 0.05; Chi² = 15.62, df = 5 (P = 0.008); I² = 68%
Test for overall effect: Z = 9.24 (P < 0.00001)

E SMD in full extension

Study or Subgroup	DLE Mean	DLE SD	DLE Total	Non-DLE Mean	Non-DLE SD	Non-DLE Total	Weight	Mean Difference IV, Fixed, 95% CI
Chen 2019	15.89	1.25	63	17.94	1.51	121	23.3%	-2.05 [-2.46, -1.64]
Huang 2016	15.2	1.8	6	16.1	1.9	52	1.7%	-0.90 [-2.43, 0.63]
Jin 2016	15.97	1.83	35	17.07	1.7	158	8.9%	-1.10 [-1.76, -0.44]
Li 2017	16.06	1.21	35	18.01	1.47	55	12.5%	-1.95 [-2.51, -1.39]
Liu 2021	14.33	0.9	52	16.28	0.69	98	49.7%	-1.95 [-2.23, -1.67]
Liu 2022	12.88	2.1	22	14.09	2.11	73	3.9%	-1.21 [-2.21, -0.21]
Total (95% CI)			**213**			**557**	**100.0%**	**-1.85 [-2.05, -1.65]**

Heterogeneity: Chi² = 9.51, df = 5 (P = 0.09); I² = 47%
Test for overall effect: Z = 18.36 (P < 0.00001)

Fig. 4. Forest plots illustrating the differences in anatomical characteristics including hyomental distance (HMD; A, B), thyromental distance (TMD; C, D), and sternomental distance (SMD; E) between the difficult laryngeal exposure (DLE) and non-DLE groups. SD, standard deviation; IV, inverse variance; CI, confidence interval.

MMI

Study or Subgroup	DLE Events	DLE Total	Non-DLE Events	Non-DLE Total	Weight	Odds Ratio M-H, Random, 95% CI
Chen 2019	43	63	43	121	10.6%	3.90 [2.04, 7.46]
Cheng 2020	76	97	77	113	10.7%	1.69 [0.91, 3.16]
Kharrat 2022	12	59	14	52	9.1%	0.69 [0.29, 1.67]
Li 2017	25	35	19	55	8.9%	4.74 [1.89, 11.89]
Liu 2021	29	52	9	98	9.2%	12.47 [5.19, 29.98]
Ma 2016	2	22	6	40	5.1%	0.57 [0.10, 3.08]
Meng 2010	7	7	14	46	2.3%	33.62 [1.80, 628.92]
Paul 2016	12	31	13	86	8.8%	3.55 [1.40, 9.02]
Pinar 2009	10	22	6	72	7.4%	9.17 [2.80, 29.96]
Sun 2015	36	64	26	93	10.5%	3.31 [1.70, 6.48]
Wang 2012	9	20	9	69	7.7%	5.45 [1.77, 16.81]
Wang 2021	15	37	29	141	9.8%	2.63 [1.22, 5.70]
Total (95% CI)		**509**		**986**	**100.0%**	**3.37 [2.07, 5.48]**
Total events	276		265			

Heterogeneity: Tau² = 0.48; Chi² = 36.54, df = 11 (P = 0.0001); I² = 70%
Test for overall effect: Z = 4.88 (P < 0.00001)

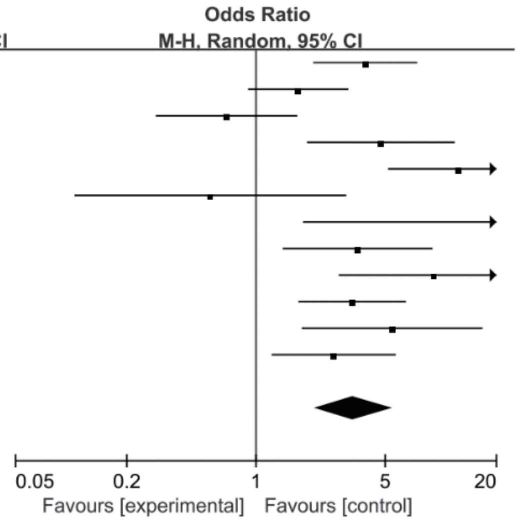


Fig. 5. Forest plot illustrating the difference in modified Mallampati index (MMI) between the difficult laryngeal exposure (DLE) and non-DLE groups. M-H, Mantel-Haenszel; CI, confidence interval.

[32-35]. Age, another parameter that showed statistically significant results, is closely related to BMI; specifically, older patients tend to display higher body fat percentages. Additionally, upper airway dimensions, such as the oropharyngeal junction, maximum pharyngeal area, and pharyngeal volume, decrease with age [36]. Considerable research indicates that although elderly individuals are more likely to have a smaller tongue due to deterioration in tongue muscle fiber size and number [37,38], they still experience DLE in conjunction with other factors such as obesity, a thick and stiff neck, and degeneration of joint and muscle function [8,29,31,34].

Regarding anatomical characteristics, the NC and neck flexion-extension angle exhibited clear discrepancies between DLE and non-DLE groups. Paul et al. [1] concluded that patients with an NC greater than 34.25 cm were about four times more likely to experience difficult laryngoscopy. IIG is another key observational index related to DLE. A sufficiently wide mouth opening is important for transoral laryngoscopy; thus, a gum elastic bougie is sometimes utilized when patients experience DLE. The absence of teeth increases the mouth space and enlarges the IIG. Some researchers have observed that the likelihood of DLE increases progressively by dental status, in the order of edentulous, partially edentulous, normal teeth, and prominent teeth [4,39,40]. Considering the various anatomical distances, even a minor difference in each one-dimensional parameter can combine to yield a significant discrepancy in the three-dimensional structure of the pharyngeal space. To an extent, the investigated parameters, such as TMD, HMD, and SMD, may collectively determine the dimensions of the upper airway. Furthermore, we classified and examined physical measurement data acquired in both the neutral position and the Boyce-Jackson sniffing position (with the head and neck in full extension), as placement in a sniffing position can facilitate laryngeal exposure [41]. Apart from HTMD, the measurements of all parameters increased in the sniffing/full extension position compared to the neutral position, validating the reliability of the synthesized data. Regarding anatomical characteristics, some high heterogeneity was observed; this could stem from measurement bias in addition to the factors mentioned above, particularly for IIG (I^2=95%) and flexion-extension angle (I^2=92%). These measurements are more challenging than other parameters to obtain with precision.

Our study also incorporated well-known parameters associated with difficult endotracheal intubation. MMI, a relatively straightforward grading system for predicting difficult intubation, was identified as a strong predictor of DLE. Merah et al. [42] previously highlighted MMI as an optimal single predictor, with a sensitivity of 61.5%, specificity of 98.4%, and positive predictive value of 57.1%. MCLS, which is closely related to MMI, did not show a significant relationship according to the findings of three studies. For both MMI (I^2=70%) and MCLS (I^2=97%), which rely on subjective judgment, visual errors are unavoidable. Direct rigid laryngoscopy and microlaryngoscopy have been employed in some studies to visualize the laryngeal cavity [1,8]. Factors such as the size, resolution, focal length, and aperture of these types of laryngoscopies may influence the extent of laryngeal exposure. Notably, unlike during anesthesia intubation, even minor differences in vocal fold exposure can impact the grading of DLE.

To date, no preoperative prediction system is available that utilizes objective parameters for DLE. Schmitt et al. [43] highlighted the predictive value of the ratio between patient height and TMD, suggesting that further investigation into the difference and ratio of existing parameters is warranted. This could include the incorporation of novel parameters such as the positioning of mandibular tori [44] and the percentage of glottic opening [45]. Wajekar et al. [33] found that a combination of the upper lip bite test, MMI, and TMD yielded the highest specificity and acceptable sensitivity for predicting difficult intubation. Kharrat et al. [14] used lateral x-ray films to assess anatomical characteristics rather than physical measurements. Additionally, various studies have employed computed tomography, radiographs, and ultrasound as tools to predict difficult airways [45]. Numerous studies [1,2,5,8,25] have applied multivariate logistic regression analysis to account for the interactions among parameters. Three studies [2,5,6] incorporated correlation analyses to examine the relationships between parameters and DLE. Moreover, several studies [1,6,8,25] have determined cut-off values for specific parameters and conducted receiver operating characteristic analysis to identify effective screening tests for DLE. In 2014, Piazza et al. [4] introduced a standardized preoperative assessment protocol, the Laryngoscore, which encompasses 11 parameters. Subsequently, Arjun and Dutta [3] and Tirelli et al. [46] carried out external validations of this protocol. In 2019, Incandela et al. [47] proposed a streamlined version of the Laryngoscore, consisting of three parameters: IIG, thyromental distance, and upper jaw dental status. The present analysis indicates significant differences in age, NC, TMD, and SMD in full extension, which should be incorporated into a DLE prediction system. Additionally, weights should be customized based on the predictive performance of different parameters. Furthermore, the preoperative prediction system should not only estimate the incidence of DLE but also recommend the optimal surgical approach and laryngoscope model for individual patients, based on sets of specific parameters. Future research should include larger, long-term follow-up studies to determine the appropriate treatment for DLE and its related complications.

In this study, we noted that the study groups employed inconsistent definitions of DLE. Consequently, we categorized the articles into four subgroups based on these definitions (Supplementary Table 6) for further analysis. Our findings revealed that while some heterogeneity was present within the different DLE definition subgroups, the heterogeneity between subgroups was generally low. This suggests that the variations in DLE definitions had a minimal effect on the overall group results (Supplementary Figs. 2-13).

In this study, we conducted the first meta-analysis aimed at identifying reliable predictors of DLE in accordance with standard guidelines, incorporating over 2,000 cases from four countries. Rigorous literature quality control was implemented to eliminate potential bias and ensure the reliability of the results. Subgroup, sensitivity, and publication bias analyses were employed to test for heterogeneity and validate our conclusions. We identified 12 valuable parameters for predicting DLE, which can assist surgeons in better managing DLE in clinical practice. However, this meta-analysis has several limitations. First, our study process included inherent biases; for instance, potential bias in defining DLE might have led to an unclear delineation between the experimental and control groups. The experience level of the surgeon also influences the likelihood of DLE in clinical practice. In their study, Paul et al. [1] noted that senior surgeons provided guidance during some of the more challenging microlaryngeal procedures. However, none of the 18 studies included in our analysis addressed this confounding factor. Moreover, most studies utilized hospital controls, consisting of patients with various laryngeal lesions, rather than the general population. This naturally increased the risk of selection bias. Additionally, the NOS star system was utilized to assess the risk of bias, with most studies scoring six or seven stars rather than eight or more, suggesting that the study designs and execution could be improved. Second, the high heterogeneity of some parameters weakened the credibility of our findings. We did not perform meta-regression due to insufficient data, study characteristics, and the number of studies. Finally, most of the studies lacked long-term follow-up to monitor patients with DLE for related complications.

A reasonable assessment of DLE can assist the surgeon in preparing an alternative surgical plan and selecting the appropriate instruments in advance, thereby reducing the likelihood of surgical failure and related complications. Our study involved a comprehensive and systematic analysis of the factors contributing to DLE. Sex, age, BMI, NC, MMI, IIG, HMD, TMD, SMD, and the flexion-extension angle were identified as predictors of DLE and should be given increased consideration in microsurgery.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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ORCID

Mengshu Wang https://orcid.org/0000-0003-0566-970X
Yong Liu https://orcid.org/0000-0001-5102-0309
Yuanzheng Qiu https://orcid.org/0000-0001-9518-388X

Huihong Chen https://orcid.org/0009-0009-5295-4918
Wang Liwen https://orcid.org/0000-0003-1239-4927
Donghai Huang https://orcid.org/0000-0002-8905-3234
Xin Zhang https://orcid.org/0000-0002-9273-6212
Guo Li https://orcid.org/0000-0001-7646-4213

AUTHOR CONTRIBUTIONS

Conceptualization: GL. Methodology: GL. Formal analysis: MW. Data curation: HC, WL. Supervision: YQ, DH, XZ. Project administration: YQ, DH, XZ. Funding acquisition: GL. Writing–original draft: MW. Writing–review & editing: YL.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found online at https://doi.org/10.21053/ceo.2023.00023.

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