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The Obstructive Sleep Apnea Physical Exam: A Systematic Review and Meta-Analysis

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ABSTRACT

Introduction: This systematic review aimed to determine the clinical utility of various physical exam findings in the diagnosis of obstructive sleep apnea (OSA).

Methods: A systematic review of English articles identified from PubMed, Embase, CENTRAL, and Web of Science databases. Search terms included "sleep apnea," "physical exam," "polysomnography," and all relevant synonyms. Two reviewers independently screened abstracts, reviewed full texts, and extracted data from all studies that presented associations between physical characteristics and apnea-hypopnea index (AHI).

Results: A total of 35 studies representing 13,854 patients were included in this review. The mean difference between high AHI and low AHI groups was 4.09 kg/m^2 (95% CI: 2.78–5.39) for BMI, 7.93 cm (3.59–12.28) for waist circumference, and 3.67 cm (2.64–4.71) for neck circumference. The odds ratios for having a high AHI were 2.44 (1.07–5.55) for macroglossia, 2.23 (1.68–2.96) for Mallampati > 2, 1.88 (1.67–2.11) for tonsil grade > 2, 3.99 (1.94–8.21) for pharyngeal grade > 2, and 1.57 (1.48–1.67) for enlarged uvula. Thyromental distance, retrognathia, Friedman grade, septal deviation, and enlarged turbinates were also assessed and were not found to be statistically significant between AHI groups.

Discussion: Several physical exams have strong evidence in the literature supporting their strength at differentiating patients with and without OSA. These should be used routinely among providers who treat OSA, regardless of specialty, to help guide decisions about recommending a sleep study and selecting appropriate treatment. Other physical characteristics may be better assessed through advanced exam techniques or require more research and standardization in the way they are assessed by practitioners.

1 | Introduction

Congenital and acquired characteristics, such as reduced size of the cranial bony structures and airway soft tissue redundancy, can make the upper airway more prone to collapse, leading to obstructive sleep apnea (OSA) [1]. While polysomnography is the gold standard for diagnosing OSA, it does not identify the anatomical sites of obstruction [2]. Furthermore, polysomnography is often difficult to access due to its complexity and cost. A thorough physical exam can aid in appropriate patient selection for sleep study referral and identify the anatomic level(s) of obstruction, guiding further advanced evaluations (e.g., cephalometric X-rays or nasal endoscopy) and eventual treatment [3].

A clinical guideline produced by The Adult OSA Task Force of the American Academy of Sleep Medicine (AASM) suggests examining obesity, neck circumference, Friedman tongue position (FTP), Mallampati classification, macroglossia, tonsillar hypertrophy, enlarged/elongated uvula, lateral peritonsillar narrowing, high arched/narrow palate, retrognathia, overjet, nasal polyps, nasal deviation, nasal valve abnormalities, and turbinate hypertrophy when assessing a patient with potential OSA [4]. Yet, many of these physical characteristics are examined inconsistently and have conflicting evidence on their ability to accurately identify patients at risk for OSA. Several physical exam findings have been shown to be significantly correlated with OSA severity, and previous studies have attempted to combine historical and physical findings to make predictive OSA tools [5–10]. However, these tools often only include a few physical findings and exclude others that may be important to routinely examine. A standardized, comprehensive physical exam to assess risk for OSA is still absent. Thus, while one anatomical area of obstruction may be treated, others may be overlooked, leading to inaccurate or incomplete treatment.

The purpose of this systematic review and meta-analysis is to examine which physical exam characteristics are associated with AHI and can clinically distinguish OSA patients from healthy controls or patients with only mild OSA.

2 | Methods

2.1 | Search Strategy

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [11]. A research librarian with expertise in conducting systematic reviews queried the PubMed, Embase, CENTRAL, and Web of Science libraries with the terms "sleep apnea," "physical exam," "polysomnography," and all relevant synonyms. Full search terms are presented in the Supporting Information. All databases were searched from inception until August 2023. Deduplication was conducted in EndNote (Clarivate 2021) [12]. Systematic study selection was conducted using the Rayyan web tool (Rayyan Systems Inc. 2016).

2.2 | Study Selection

Studies that correlated upper aerodigestive tract physical characteristics to AHI were included. Studies that examined physical characteristics that are not easily assessed in an average clinical setting and require advanced imaging or techniques (i.e., CINE MRI, cephalometric X-rays or CT, endoscopy) were not included. The full inclusion/exclusion criteria are presented in Table 1. Two reviewers (N.P. and A.V.) independently reviewed abstracts and full texts. Conflicts were discussed between the reviewers and resolved by consensus. Quality assessment was conducted using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [13].

2.3 | Data Extraction

Two reviewers (N.P. and B.P.) independently extracted data and compared results for accuracy. Extracted data included author, year of publication, country where the study was conducted, sample size, age, sex distribution, physical exam measurements between different AHI groups, and correlation *p*-value between physical exam and AHI, if available.

TABLE 1 | Inclusion and exclusion criterion.

Criteria category	Inclusion criteria	Exclusion criteria
Participants	Nonsyndrome adult subjects ≥ 18 years of age with a diagnosis of OSA by overnight PSG or overnight sleep study	Children (age < 18 years) syndromic subjects.
Interventions/investigations	Studies evaluating physical characteristics in adult OSA subjects using at least one clinically observable assessment of upper aerodigestive tract structures	Studies evaluating physical characteristics using advanced modalities (i.e., cephalogram, endoscopy)
Comparator (control)	If available, individuals without OSA or with mild OSA	N/A
Outcome	Studies providing physical exam parameters in a quantitative or qualitive measurement	Studies not providing quantitative or qualitative measurements and focusing on treatment and surgery of OSA rather than diagnosis
Study design	Randomized controlled trials Cohort studies Case control studies Cross-sectional studies	Survey studies Reviews articles Systematic reviews Meta-analysis Animal studies/testing Case reports Language other than English

Abbreviations: OSA, obstructive sleep apnea; PSG, polysomnography.

2.4 | Statistical Analysis

Studies that compared physical exam findings based on AHI classes (either moderate/severe OSA vs. mild OSA, or OSA vs. healthy controls) were included in a meta-analysis. Physical exam findings with three or more studies were included in the pooled analysis—exam findings with fewer than three studies were qualitatively assessed for their associations with AHI. All statistical analysis was performed using the metafor (Version 4.0-0) and meta (Version 6.2-1) packages in R (Version 4.3.0; R Project for Statistical Computing). Random-effect models using the Restricted maximum likelihood (REML) estimator were created for mean differences for continuous variables and odds ratios for binary variables. Heterogeneity was reported as low (Higgin's $I^2 = 0\%–25\%$), moderate ($I^2 = 26\%–50\%$), or high ($I^2 > 50\%$), along with [2] and χ^2 statistics. Formal heterogeneity hypothesis testing was evaluated with Cochran's Q-test. Outlier analysis was performed using influential case diagnostics and leave-one-out testing, which were reported in the body of the results but not removed from the analysis. Publication bias was assessed with funnel plots and Egger tests using a mixed-effects meta-regression model.

For continuous variables, averages for the high AHI and low AHI groups, mean differences, 95% confidence intervals, study weight, and pooled mean differences with reference line and confidence interval are reported. For binary variables (when continuous variables were not available), counts for the high AHI and low AHI groups and odds ratios are instead reported. A significance level of $p = 0.05$ was used for all analyses.

3 | Results

Overall, 35 studies including 13,854 patients were included (Figure 1, Table 2) [8, 9, 14–46]. Of the 35 studies, 37.1% were published in otolaryngology journals, 25.7% in sleep medicine journals, and 11.4% in pulmonology journals. Other specialties represented include internal medicine, anesthesiology, and dentistry. Data was extracted for four continuous variables and 9 binary variables. These data were separated into two groups (high versus low AHI) and the mean differences or odds ratios were compared. The cutoffs for low versus high AHI ranged from 5 to 15 between the different studies. The studies included in the meta-analysis and the physical exams they reviewed are

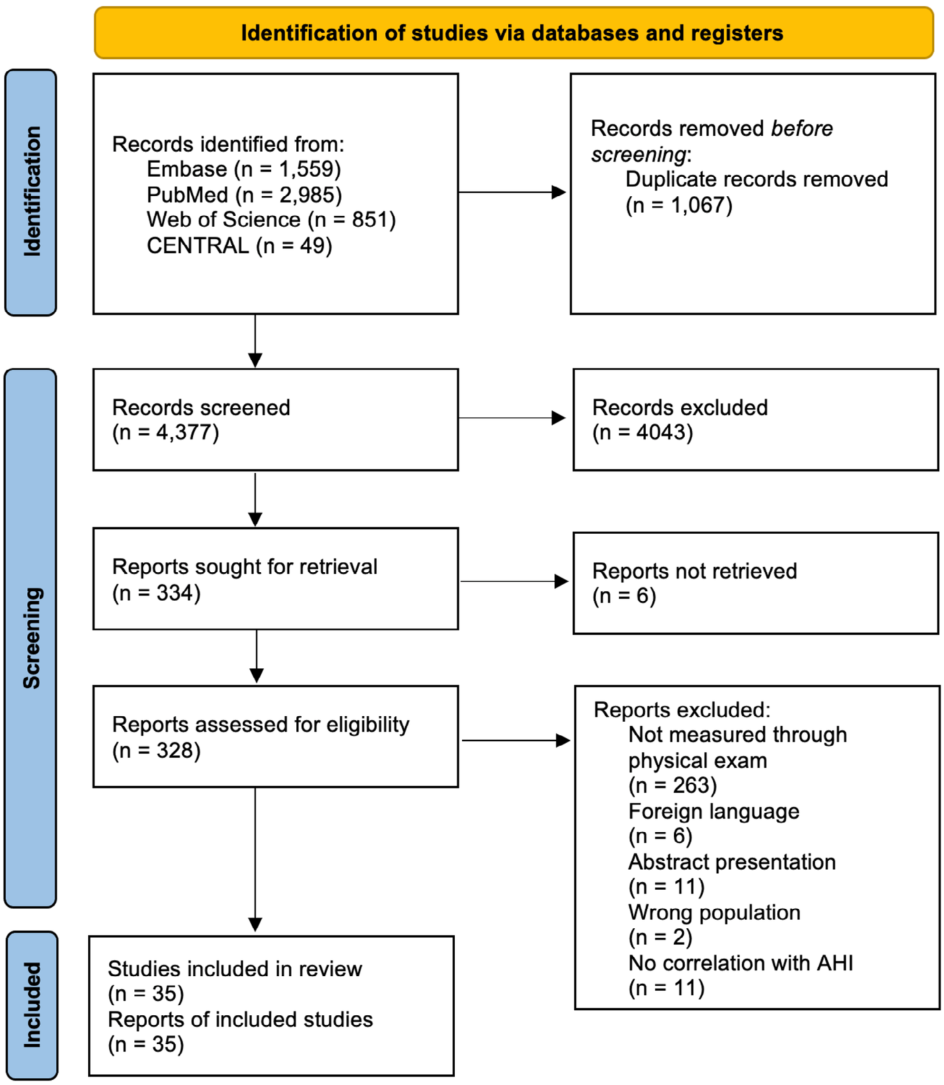

FIGURE 1 | PRISMA diagram for search methodology.

TABLE 2 | Study characteristics.

Author, year, country	*n*	Age	% Female	Significant association w/AHI	Nonsignificant association w/AHI
Ahn, 2015, Korea	64	43.8 (12.3)	0	BMI, Mallampati, Hyomental distance	Friedman
Ashraf, 2022*, India	120	47.2 (14.1)	23.3	BMI, NC, Mallampati, Macroglossia, narrow dental arch	Facial profile
Banabilh, 2010*, Malaysia	120	18–65	52.5	BMI, NC, Facial profile shape, Malocclusion class	Palatal shape
Banhiran, 2013*, Thailand	283	48.7 (11.6)	41.7	BMI, NC, WC, Cricomental distance	Friedman, Tonsil size, Hyomental distance, Thyromental distance
Barceló, 2011, Spain	301	18–82	28.9	BMI, NC, Friedman, Tonsil size, Uvula	—
Dahlqvist, 2007, Sweden	801	50.5 (11.3)	25.6	Male: BMI, NC, Tonsil size, Uvula; Female: Retrognathia	Male: Retrognathia; Female: NC, BMI, Tonsil size, Uvula, Macroglossia
de Athayde, 2023, Brazil	80	46.8 (13.0)	0	BMI, NC, WC, Mallampati	—
He, 2022*, China	202	18–68	22.3	BMI, NC, Tonsil size, Pharyngeal grade, Peritonsillar narrowing, Septal deviation	Hypertrophic inferior turbinates
He, 2021*, China	197	18–68	21	BMI, NC, Tonsil size, Pharyngeal grade, Peritonsillar narrowing	Mallampati, Macroglossia, Deviated septum, Hypertrophic inferior turbinate
Hiremath, 1998*, Australia	30	35–76	13.3	Mallampati, NC, Decreased head extension	Thyromental distance
Hukins, 2010, Australia	953	50 (6.4)	65	BMI, Mallampati	—
Jara, 2019, USA	83	43 (12)	39	Tonsil size	—
Laharnar, 2021, International	150	57.5 (12.3)	40	BMI, NC, WC, Mallampati	—
Lai, 2014, Taiwan	51	27–62	9.8	Tonsil size	—
Lam, 2005*, Canada/China	239	49 (12)	17	Mallampati, Thyromental angle	BMI, NC, Thyromental distance
Lin, 2019, Taiwan	325	20–65	15.7	NC, WC, HC, BMI, Friedman, Tonsil size, Uvula, Thyromental distance	Hyomental distance
Meskill, 2021, USA	1708	18–90	47.2	BMI, NC, Simmons Chin Press and Tongue Curl	—
Nuckton, 2006*, USA	137	46 (12)	28	BMI, NC, Mallampati	—
Oliveira, 2015*, Brazil	993	41.8 (0.9)	53.9	BMI, NC, Tonsil size, Uvula, Mallampati, Septal deviation	Retrognathia, High arched palate, Dental occlusion, Inferior turbinate hypertrophy
Pang, 2016, USA	102	24–76	36.3	BMI, Mallampati, Friedman	—
Park, 2021, Korea	3432	46.2 (13.5)	18.4	BMI, NC, WC, HC, Tonsil Size, Macroglossia, Uvula	—
Pawar, 2018, India	193	25–82	23.3	BMI, NC, Mallampati, Tonsil size	Retrognathia, Macroglossia, Uvula, High arched palate

(Continues)

TABLE 2 | (Continued)

Author, year, country	*n*	Age	% Female	Significant association w/AHI	Nonsignificant association w/AHI
Remya, 2016*, India	76	25–50	0	Mallampati	BMI, NC, WC, HC, Thyromental distance, Thyromental angle
Schwab, 2017*, USA	860	47.4 (13.7)	52.1	BMI, Mallampati, Pharyngeal grade	Tonsil size, Macroglossia
Soares, 2006*, Brazil	80	18–71	32.5	BMI, NC	Retrognathia, Palatal Height
Svensson, 2005*, Sweden	132	51.3 (10.1)	100	BMI	Tonsil size, Palatal height, Retrognathia, Septal deviation, Uvula, Macroglossia
Thong, 2008, Singapore	84	22–66	17.9	BMI, Mallampati	Tonsil size
Ucok, 2011*, Turkey	98	48.8 (9.0)	0	Mallampati	BMI, WC, HC
Weihu, 2010*, China	103	32–75	35	BMI, NC, Mallampati	Tonsil size, Fauce's narrowness scale
Wu, 2010*, Taiwan	244	43.1 (12.1)	27	BMI	Mallampati, Tonsil size
Wysocki, 2015, Poland	138	50.7 (11.6)	12.3	BMI, NC, WC, HC, Friedman	Pirquet's Score
Yagi, 2009*, Japan	141	49 (14)	22	BMI, NC, Mallampati, Tonsil size, Fauce's narrowness scale	Retroglossal space
Yilmaz, 2017*, Turkey	147	47.8 (9.0)	32	BMI, NC, Thyromental distance	—
Yuceege, 2014*, Turkey	185	46.3 (10.3)	34.1	BMI, NC, Neck/thyromental ratio	Thyromental distance
Zhang, 2022*, China	1002	35–55	17.5	BMI, NC, Uvula, Tonsil size, Pharyngeal stenosis, Macroglossia, Retrognathia	Septal deviation, Turbinate hypertrophy, Friedman

Note: Studies marked with asterisks were included in the meta-analysis. Age is presented as mean (SD) or range.
Abbreviations: HC, hip circumference; NC, neck circumference; WC, waist circumference.

TABLE 3 | Summary of results from meta-analysis.

Physical exam	# of studies	Low AHI n	High AHI n	OR or mean difference (95% CI)	Heterogeneity (I^2), p
Anthropometrics					
BMI (kg/m^2)	13	1569	1888	**4.09 (2.78–5.39)**	91.0%, < 0.001
Waist (cm)	3	165	292	**7.93 (3.59–12.28)**	0.0%, 0.525
Neck (cm)	13	1258	1434	**3.67 (2.64–4.71)**	98.6%, < 0.001
Craniofacial measurements					
Thyromental (cm)	6	323	637	−0.78 (−1.84–0.28)	100.0%, < 0.001
Retrognathia	3	1005	1122	1.30 (0.78–2.18)	99.4%, < 0.001
Oral cavity/oropharynx					
Macroglossia	5	1398	1711	**2.44 (1.07–5.55)**	99.7%, < 0.001
Mallampati Grade (≤ 2 vs. > 2)	7	1337	1286	**2.23 (1.68–2.96)**	86.3%, < 0.001
Friedman Grade (≤ 2 vs. > 2)	3	569	1014	5.94 (0.26–133.64)	91.6%, < 0.001
Tonsil Grade (≤ 2 vs. > 2)	7	1254	1079	**1.88 (1.67–2.11)**	1.2%, < 0.420
Pharyngeal Grade (≤ 2 vs. > 2)	3	317	505	**3.99 (1.94–8.21)**	97.9%, < 0.001
Enlarged Uvula	3	1005	1122	**1.57 (1.48–1.67)**	61.6%, < 0.001
Nasal cavity					
Septal deviation	5	1132	1394	1.37 (0.87–2.16)	95.7%, < 0.001
Enlarged turbinates	7	1068	1326	1.02 (0.81–1.29)	98.3%, < 0.001

Note: Mean differences are presented for continuous variables, while odds ratios are presented for binary variables. Significant results are bolded.

summarized in Table 3. The remaining studies were not included in the meta-analysis because they focused on physical exams where there were fewer than three studies evaluating them or because of heterogeneity in the reported statistics, but they are reported in Table 2.

3.1 | Anthropometrics

3.1.1 | BMI

There were 13 studies included for BMI (Figure 2). The pooled difference was 4.09 kg/m^2 (2.78–5.39, 95% CI; $p < 0.0001$). Patients with high AHI tend to have higher BMIs than those with low AHI. There was high heterogeneity between studies ($I^2 = 91.0\%$; $\tau^2 = 5.11$; $Q = 133.93$; $p < 0.0001$). This suggests that the true difference in BMI between high and low AHI groups varies between studies. Case diagnostics found Banabilh et al. 2010 to potentially be an influential study (Supporting Information Figure 1). However, removing this study did not significantly change the pooled differences (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.316$).

3.1.2 | Waist Circumference

There were three studies included for waist circumference (Figure 2). The pooled difference was 7.93 cm (3.59–12.28, 95% CI; $p = 0.0003$). Patients with high AHI tend to have higher waist circumference than those with low AHI. There was low heterogeneity between studies ($I^2 = 0.0\%$; $\tau^2 = 0$; $Q = 1.29$; $p = 0.525$). This suggests all studies shared the same true difference in waist circumference. Ucok et al. 2011 was an influential study, but excluding it did not change pooled differences in waist circumference (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.994$).

3.1.3 | Neck Circumference

There were 13 studies included for neck circumference (Figure 2). The pooled difference was 3.67 cm (2.64–4.71, 95% CI; $p < 0.0001$). Patients with high AHI tend to have higher neck circumference than those with low AHI. There was high heterogeneity between studies ($I^2 = 98.6\%$; $\tau^2 = 3.31$; $Q = 861.42$; $p < 0.0001$). This suggests that the true difference in neck circumference between high and low AHI groups varies between

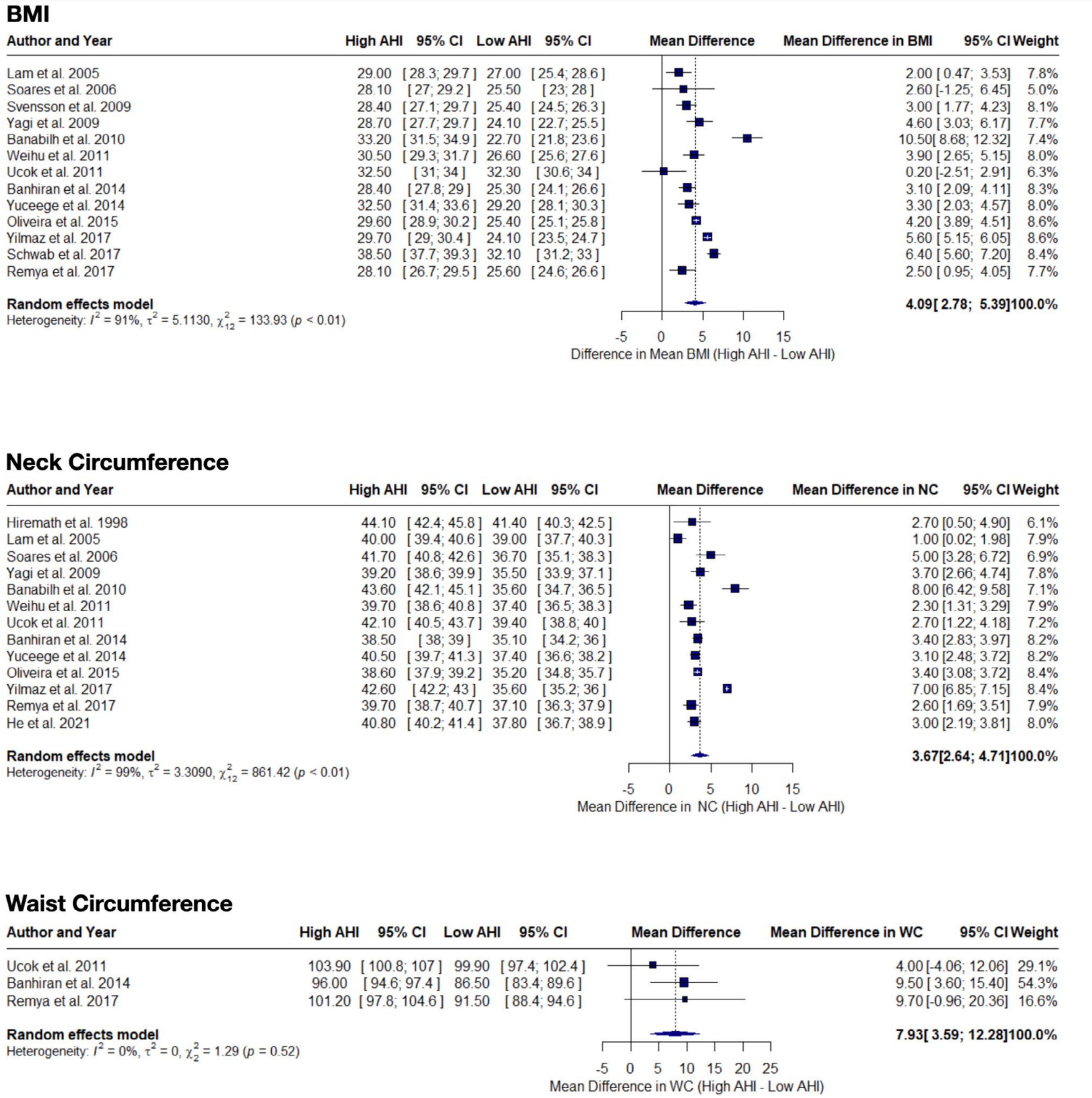

FIGURE 2 | Forest plots for anthropometric measurements. Horizontal lines depict 95% confidence intervals, square size represents the study weight, and the diamond width shows the pooled 95% confidence interval.

studies. No influential cases were identified on case diagnostics and leave-one-out testing (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.641$).

3.2 | Craniofacial Measurements

3.2.1 | Thyromental Distance

There were six studies included for thyromental distance (Figure 3). The pooled difference was −0.78 cm (−1.84 to 0.28, 95% CI; $p = 0.147$). There was no difference in thyromental distance between the high and low AHI groups. There was high heterogeneity between studies ($I^2 = 100\%$; $\tau^2 = 1.74$; $Q = 10338.11$; $p < 0.0001$). This suggests that the true difference in thyromental distance between high and low AHI groups varies between studies. Yilmaz et al. 2017 was an influential study (Supporting Information Figure 1). Excluding this study reduced the difference between groups, further supporting that there is no difference in thyromental distance (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.897$). Of note, these studies represented assessments in the clinic and did not include radiographic or cephalometric exams.

3.2.2 | Retrognathia

There were three studies included for retrognathia (Figure 3). The pooled odds ratio was 1.30 (0.78–2.18, 95% CI; $p = 0.315$). Patients with retrognathia are not at greater odds of high AHI than those without. There was high heterogeneity between studies ($I^2 = 99.4\%$; $\tau^2 = 0.197$, $Q = 0.4433$; $p < 0.0001$). Zhang et al. 2022 and Oliveira et al. 2015 were influential cases, but excluding either study did not significantly change the pooled odds ratio (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.891$). Of note, these studies represented assessments in the clinic and did not include radiographic or cephalometric exams.

3.3 | Oral Cavity/Oropharynx

3.3.1 | Macroglossia

There were five studies included for macroglossia (Figure 4). The pooled odds ratio was 2.44 (1.07–5.55, 95% CI; $p = 0.051$). Patients with macroglossia are at greater odds of having high AHI than those without. There was high heterogeneity between studies ($I^2 = 99.7\%$; $\tau^2 = 0.870$, $Q = 1375.514$; $p < 0.0001$). Ashraf et al. 2022 was identified as an influential study, though excluding this study did not change the pooled odds ratio (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.293$).

3.3.2 | Mallampati

There were nine studies included for Mallampati classification (Figure 4). The pooled odds ratio was 3.20 (1.94–5.27, 95% CI; $p < 0.0001$). Again, Ashraf et al. 2022 was identified as an influential study and excluding this study lowered the pooled odds ratio by 0.8 to 2.45 (data not shown). The funnel plot suggested publication bias, specifically for Ashraf et al. 2022 and Ucok et al. 2011 (data not shown). The Egger test also suggested publication bias ($p = 0.0226$). If Ashraf et al. 2022 is excluded, a similarly significant publication bias is found and still identifies Ucok et al. 2011 as an influential study. Therefore, we opted to exclude both Ashraf et al. 2022 and Ucok et al. 2011. If both are excluded, the pooled odds ratio is 2.23 (1.68–2.96, 95% CI; $p < 0.0001$). Patients with high Mallampati class are at greater odds of having high AHI than those with low Mallampati class. There was high heterogeneity between studies ($I^2 = 86.3\%$; $\tau^2 = 0.126$, $Q = 43.6$; $p < 0.0001$). Oliveira et al. 2015 was identified as an influential study within these remaining seven studies, but excluding it did not significantly change the pooled outcome (Supporting Information Figure 1). Furthermore, the funnel plot did not suggest publication bias, nor did the Egger test ($p = 0.240$) (Supporting Information Figure 2).

3.3.3 | Friedman Tongue Position

There were three studies included for Friedman classification (Figure 4). The pooled odds ratio was 5.94 (0.26–133.64, 95% CI; $p = 0.262$). Patients with a high FTP were not at significantly greater odds of having high AHI than those with low FTP. There was high heterogeneity between studies ($I^2 = 91.6\%$; $\tau^2 = 7.23$, $Q = 23.85$; $p < 0.0001$). Barcelo et al. 2011 was an influential case. Additionally, removing any single study would significantly change the pooled results (Supporting Information Figure 1). The funnel plot suggested publication bias by the Egger test (Supporting Information Figure 2, $p = 0.026$). However, because there were only three studies included in this analysis, this was difficult to interpret. Therefore, we included all three studies in this analysis but recommend a guarded interpretation.

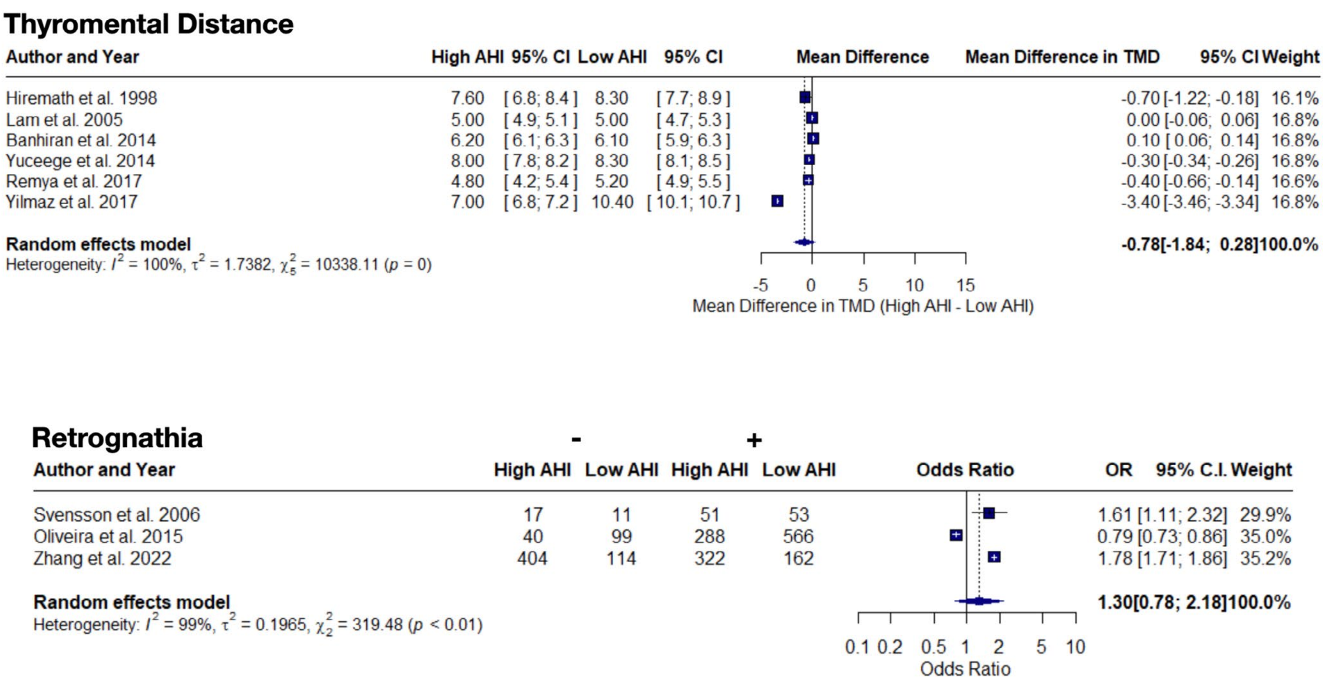

FIGURE 3 | Forest plots for craniofacial measurements. Horizontal lines depict 95% confidence intervals, square size represents the study weight, and the diamond width shows the pooled 95% confidence interval.

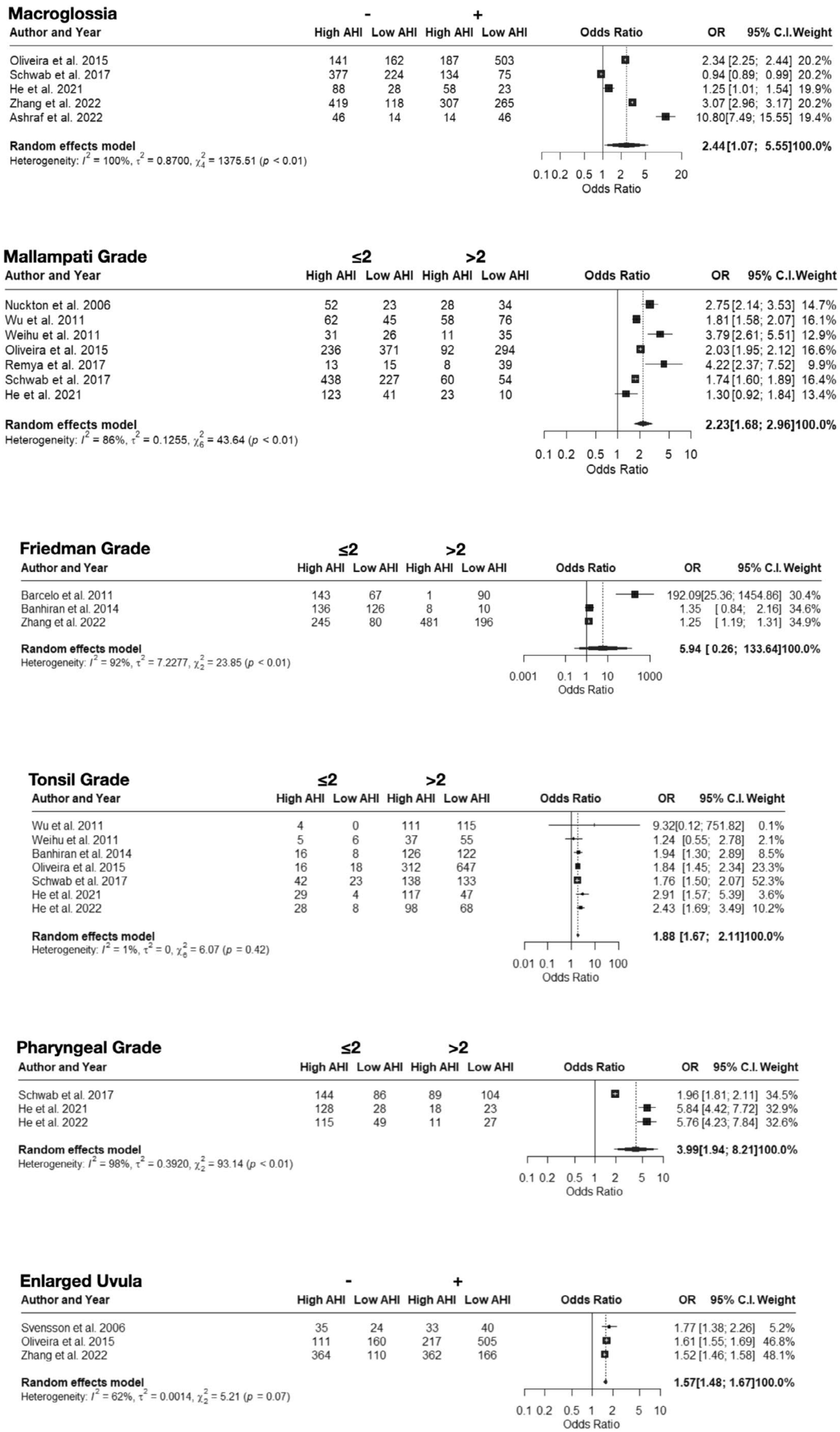

FIGURE 4 | Forest plots for oral cavity/oropharyngeal measurements. Horizontal lines depict 95% confidence intervals, square size represents the study weight, and the diamond width shows the pooled 95% confidence interval.

3.3.4 | Tonsillar Hypertrophy

There were three studies included for tonsil size (Figure 4). The pooled odds ratio was 1.88 (1.67–2.11, 95% CI; $p < 0.0001$). Patients with large tonsils are at greater odds of high AHI than those with small tonsils. There was low heterogeneity between studies ($I^2 = 1.2\%$; $\tau^2 = 0$, $Q = 6.07$; $p < 0.0001$). No studies were identified as outliers on influential case diagnostics or leave-one-out testing (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.356$).

3.3.5 | Pharyngeal Grade

There were three studies included for pharyngeal grade (Figure 4). The pooled odds ratio was 3.99 (1.94–8.21, 95% CI; $p = 0.0002$). Patients with high pharyngeal grade are at greater odds of having a high AHI than those with low pharyngeal grade. There was high heterogeneity between studies ($I^2 = 97.9\%$; $\tau^2 = 0.392$, $Q = 93.14$; $p < 0.0001$). Schwab et al. 2017 was an influential case. Excluding it significantly increased the pooled odds ratio to 5.80 (OR 2.19–9.41), but this finding was still statistically significant (Supporting Information Figure 1). The funnel plot suggested publication bias by the Egger test (Supporting Information Figure 2, $p = 0.001$). This was difficult to interpret as there were only three studies that reported pharyngeal grade. Therefore, we included all three studies in this analysis but recommend a guarded interpretation.

3.3.6 | Enlarged Uvula

There were three studies included for enlarged uvula (Figure 4). The pooled odds ratio was 1.57 (1.48–1.67, 95% CI; $p < 0.0001$). Patients with an enlarged uvula were at greater odds of having high AHI than those with small uvulas. There was high heterogeneity between studies ($I^2 = 61.6\%$; $\tau^2 = 0.0014$), though formal heterogeneity testing failed to reach significance ($Q = 5.21$; $p = 0.074$). This suggests that the true odds ratio varies between studies. No influential cases were identified on case diagnostics and leave-one-out testing (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.732$).

3.4 | Nasal Cavity

3.4.1 | Septal Deviation

There were five studies included for septal deviation (Figure 5). The pooled odds ratio was 1.37 (0.87–2.16, 95% CI; $p = 0.173$). Patients with septal deviation are not at greater odds of high AHI than those without. There was high heterogeneity between studies ($I^2 = 95.7\%$; $\tau^2 = 0.261$, $Q = 93.82$; $p < 0.0001$). Svensson et al. 2006 was an influential case. influential cases, but excluding either study did not significantly change the pooled odds ratio (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.419$).

3.4.2 | Turbinate Hypertrophy

There were seven studies included for turbinate hypertrophy (Figure 5). The pooled odds ratio was 1.02 (0.81–1.29, 95% CI; $p = 0.861$). Patients with turbinate hypertrophy are not at greater odds of high AHI than those without. There was high heterogeneity between studies ($I^2 = 98.3\%$; $\tau^2 = 0.0524$, $Q = 180.43$; $p < 0.0001$). Zhang et al. 2022 and Oliveira et al. 2015 were influential cases, but excluding either study did not significantly change the pooled odds ratio (Supporting Information Figure 1). The funnel plot did not suggest publication bias, nor did the Egger test (Supporting Information Figure 2, $p = 0.817$).

4 | Quality Assessment

No studies were excluded from this study through the quality assessment. The study populations were diverse, especially since the included studies were conducted in many different countries, which may introduce heterogeneity but increases the representation of the global population of patients with OSA. Variation in the studies was also found with respect to their definitions of hypopneas: the AASM defines a hypopnea as a reduction in airflow with a 3% desaturation or cortical arousal; however, a 4% desaturation without consideration of cortical activity can also be used. AHI can vary based on which definition is used [47]. The studies included in this review may differ in which definition they used, as some did not specify. Likewise, some studies did not describe their physical exam protocols in detail, as physical exams are rarely standardized, contributing to poorer quality.

5 | Discussion

The anatomic source of obstruction in OSA can occur to varying degrees at multiple sites in the upper airway. Multilevel obstruction has been associated with more severe OSA [48]. Identifying only one area of obstruction in a patient with multilevel disease may lead to incomplete treatment, which may partially explain the high rates of treatment failure seen in OSA [49]. As such, it is imperative to qualitatively assess and quantitatively measure physical characteristics in all patients with suspected OSA through a detailed anatomic physical exam.

This systematic review and meta-analysis identified several physical exam findings that have statistically significant associations with AHI. Anthropometric measures, including BMI, waist circumference, and neck circumference, were all significantly higher in patients with higher AHI. Craniofacial measurements, including retrognathia and thyromental distance, were not found to be significantly different between AHI groups. Among measurements of oral cavity/oropharyngeal crowding, Mallampati and macroglossia were found to be significant, while FTP was not. The other oropharyngeal physical characteristics included in this analysis were all significant, with patients having increased odds of having a higher AHI if they had > 2 tonsil grade, > 2 pharyngeal grade, or an enlarged uvula. Finally, nasal septal deviation and inferior turbinate hypertrophy were not significant.

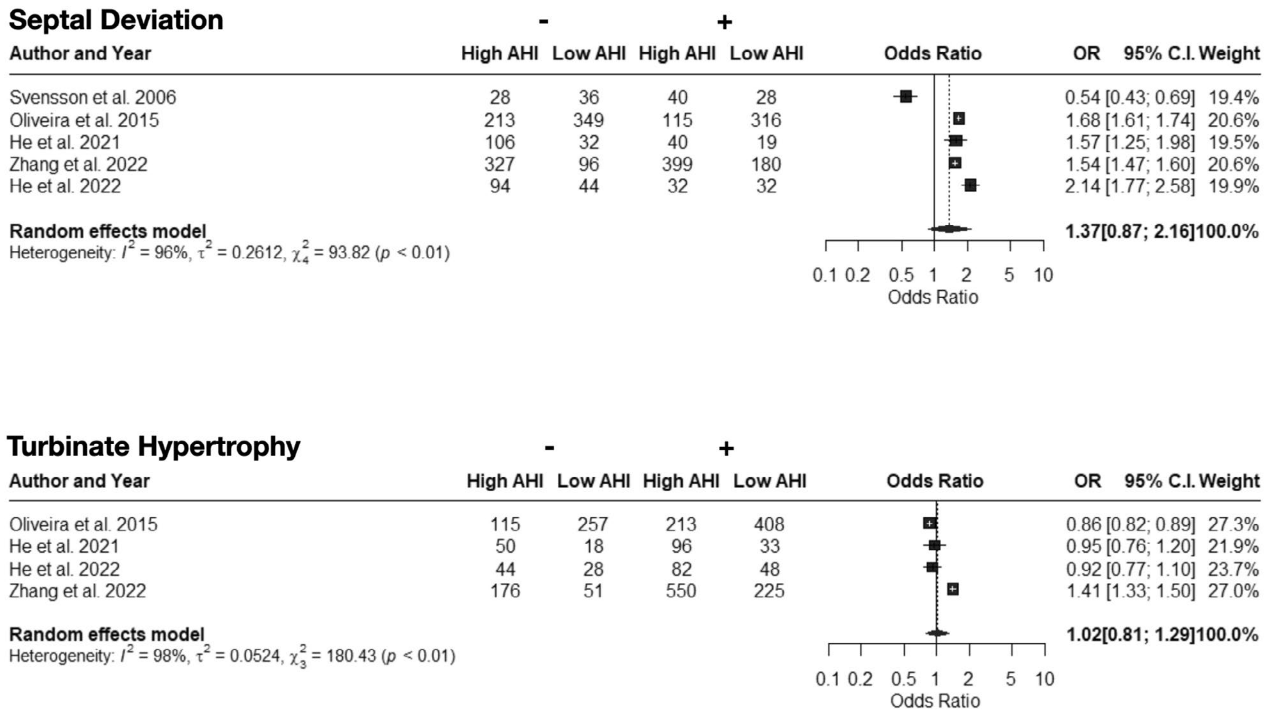

FIGURE 5 | Forest plots for nasal cavity measurements. Horizontal lines depict 95% confidence intervals, square size represents the study weight, and the diamond width shows the pooled 95% confidence interval.

BMI and neck circumference are well-established risk factors for OSA. Obesity increases the size of the soft tissue structures surrounding the airway through fat deposition [50]. Furthermore, increased abdominal fat decreases lung volumes, which reduces pharyngeal wall tension forces and makes collapse more likely [51]. The strong association between OSA and obesity is further evidenced by the fact that a 10% increase in weight is associated with a sixfold increase in the risk of developing OSA [52]. Along with BMI, neck circumference and waist circumference have both been identified as markers of central obesity [53]. The evidence from this review suggests that these measurements should routinely be included when examining patients with suspected OSA.

The craniofacial structural characteristics examined in this study through clinical assessment—retrognathia and thyromental distance—were not found to be significantly associated with AHI. These results suggest that more advanced techniques may be better suited to accurately examine these physical characteristics than clinical soft tissue measurements. A previous meta-analysis on cephalometric radiograph measurements found statistically significant differences in both mandibular length (retrognathia) and hyomental distance between patients with lower AHI compared to those with higher AHI [3]. Furthermore, nonsyndromic craniofacial characteristics that contribute to OSA are relatively rare compared to more common causes like obesity, making it difficult to detect statistically significant associations for these features. Similarly, in the nasal cavity, septal deviation and inferior turbinate hypertrophy were also not significant, suggesting nasal endoscopy may be needed to better evaluate this area. No studies examined the hypopharynx, which was expected, as this level is not readily observable through traditional examination techniques. Drug induced sleep endoscopy can be used to better examine these sites and has been shown to decrease failure rates for patients undergoing surgical treatment for OSA [54]. In addition to providing a better assessment of certain upper airway structures, endoscopy can also rule out more serious pathologies; a previous scoping review found that although rare, head and neck neoplasms can present as OSA. On average, patients had symptoms of OSA for 2.5 years until the correct diagnosis was made using endoscopy [55].

Of the five studies that examined macroglossia, different measurement techniques were used: some defined ridging on the tongue due to tooth pressure as evidence of an enlarged tongue, while others used the relationship of the tongue to the occlusion plane. There was significant heterogeneity in the odds ratios found in these studies, ranging from 0.94 to 10.80. This variability suggests that while macroglossia is a well-known risk factor for OSA, using unstandardized, subjective assessments may result in inaccurate classification of patients. A previous study found high rates of inter-observer discordance when making treatment decisions for OSA [56]. The variability in exam techniques may explain this.

When using more standardized assessments that consider tongue size, Mallampati grade was significant while FTP was not. Both these scales assess crowding of the oral cavity and oropharynx by grading the visibility of the tonsillar pillars, uvula, and soft palate on a scale of 1–4; however, in Mallampati grade, the tongue is maximally extended while it remains in a neutral position for FTP. Even when using these standardized scales, some studies have found interrater reliability to be poor. Both these scales have been shown to be associated with OSA in past studies, but the correlations have been weak. However, having a score of 1 or 2 does appear to help rule out OSA better than a score of 3 or 4 helps rule it in [57]. Consequently, these previous results in the context of the present study suggest that low

Mallampati grade may be used to decrease a clinician's index of suspicion for OSA.

The specialties that treat OSA are diverse, with this review identifying studies published in the otolaryngology, sleep medicine, pulmonology, dentistry, anesthesiology, neurology, and internal medicine literature. A comprehensive physical exam may ensure that patients with OSA are appropriately referred to specialists when advanced diagnostics or differential treatment strategies are needed. Once a patient is referred to a specialist, a broad physical exam should still be employed in case further referral to another specialty is required. A previous study found that only 35% of patients who have failed treatment with continuous positive airway pressure (CPAP) are referred for further evaluation or alternative management strategies [58]. When untreated, the sequelae of OSA are significant, including worsening hypertension and ischemic heart disease [59]. Thus, a comprehensive physical exam is especially crucial in patients who have failed CPAP therapy, as identifying anatomic sites of obstruction can guide future interventions, such as surgery. Importantly, surgical success in OSA has been shown to depend on preoperative physical exam findings [60, 61]. Comprehensive treatment for patients who have failed CPAP may also be achieved through a multidisciplinary "sleep board," where the "tumor board" model for cancer care is followed to ensure adequate communication and evaluation completeness between specialists [62].

The main limitation to this study was the high heterogeneity. This likely stems from the fact that the OSA patient population is very heterogeneous and the OSA physical exam is vulnerable to interrater variation. The physical characteristics of patients with OSA have been shown to vary widely based on ethnicity/race and sex [63, 64]. One study included in this review that presented its results separately for males and females found that different characteristics were associated with AHI between the sexes (e.g., BMI and neck circumference were significant in males but not females) [18].

Additionally, many of the physical characteristics assessed do not have a standardized protocol for measurement. This led to significant variation between studies in the exact technique that was used to measure each parameter. Examples of the different techniques used are presented in Supporting Information Table 1. The variation was especially apparent for physical exam findings that do not have a commonly used standardized rating system; for example, for features such as uvula size and jaw position, some authors had specific measurements they used to identify potentially pathologic variants, while other authors simplified subjectively identified patients without concrete measurements. Even in exams that have a standardized protocol, interrater reliability may arise. Previous studies have found varying interrater reliability for Mallampati grade ($\kappa = 0.31$–1.00), FTP ($\kappa = 0.36$–0.82), and Tonsil size (intraclass correlation coefficient $= 0.763$) [57, 65–68]. The interrater reliability for many other physical exam findings has not been studied. This highlights the need for standardized exam techniques to ensure results can be interpreted between providers and appropriate treatment protocols are followed.

Finally, publication bias was observed in FTP and pharyngeal grade. Consequently, the interpretability of these results is limited, but no studies were excluded from these analyses since the Egger test is less reliable when used in analyses with less than 10 studies [69]. Despite these limitations, this review demonstrated that many physical exam findings correlate with AHI and may be important components of a structured, multilevel, reproducible physical exam to diagnose the underlying cause of OSA. More research is needed to optimize exam technique and create standardized exam protocols.

6 | Conclusion

A comprehensive physical exam for patients with OSA is important to guide adequate treatment. While polysomnography may confirm a diagnosis of OSA, it does not preclude a careful and thorough anatomically based physical exam. Moreover, weight management and CPAP therapy have varied tolerances and adherence over time, further underscoring the need for an accurate, anatomically based exam to guide other management options. This systematic review and meta-analysis found several significant associations between physical exam characteristics and AHI. These may be important to include in a comprehensive physical exam. Several other physical findings may also have clinical utility but may be better assessed through more advanced techniques, such as endoscopy or cephalometric radiographs. The heterogeneity found in this study also highlights the need for more standardization in the way the physical exam is executed to ensure treatment decisions are consistent and appropriate.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.