Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Comparative Assessment of Nasal, Nasopharyngeal and Pharyngeal Dimensions as Correlates of Obstructive Sleep Apnea in Adults: A Cross-Sectional Cone-Beam Computed Tomography Study Tomography Study

Svitlana Koval

sve.koval@icloud.com

DrKoval Orthodontics

Daria Chepanova

DrKoval Orthodontics

Andrii Babii

Nova Southeastern University

Nika Stepanoff

DrKoval Orthodontics

Mariia Tlumak

DrKoval Orthodontics

Andrew Wellman

Harvard University

Research Article

Keywords: Cone-beam CT, upper airway, Obstructive Sleep apnea, adults, CBCT

Posted Date: November 2nd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11381330/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background/Objectives:

Studies of craniofacial contributors to obstructive sleep apnea (OSA) have focused predominantly on pharyngeal volume and minimum cross-sectional area, while the anterior upper airway has received little attention. We aimed to determine whether nasal base width, measured at the horizontal plate of the palatine bone, is associated with OSA status in adults.

Methods

In this cross-sectional study, 92 consecutive adults (49 with OSA, 43 without) presenting to a private orthodontic practice between January 20246 and June 2026 were evaluated. Nasal base width, minimum and maximum nasal width, PNS-PPW, UPPW, minimum cross-sectional area, upper airway length and the SN-GoMe angle were measured on cone-beam computed tomography volumes. OSA status was established by two nights of seven-channel home sleep apnea testing incorporating electroencephalographic recording. OSA severity was quantified using the apnea-hypopnea index (AHI, all apneas plus hypopneas with ≥ 3% oxygen desaturation/hour). Multivariable logistic regression was adjusted for sex, age and body mass index.

Results

Nasal base width was not associated with OSA status (OR 1.07 per mm, 95% CI 0.91–1.26, p = 0.386), nor was minimum cross-sectional area (OR 1.00, p = 0.988). In exploratory analyses, PNS-PPW was inversely associated with OSA (OR 0.83 per mm, 95% CI 0.73–0.95, p = 0.008; marginal effect − 3.5 percentage points per mm), with an area under the curve of 0.77. The association persisted after exclusion of influential observations and under bootstrap resampling. No other dimension was associated with OSA status.

Conclusions

Nasal base width did not discriminate OSA status in this sample. Sagittal nasopharyngeal depth at the posterior nasal spine warrants prospective evaluation.

Introduction

Upper airway assessment has become a part of the routine Cone-beam Computer Tomography (CBCT) evaluation process during orthodontic treatment. Several studies have shown that not only Skeletal Classification (I, II, or III) contributes to the difference in upper airway dimensions, but the vertical growth type (hypo-, normo-, or hyperdivergent) does either. Thus, AlAskar and colleagues [1] have shown that

nasal cavity and nasopharyngeal volumes are significantly larger in Skeletal Class I patients compared to Skeletal Class II and III. Additionally, Al-Somairi and coauthors [2] have concluded that Skeletal classes do not significantly differ in maxillary and mandibular width measurements, but rather vary in vertical maxillary position (Class II patients have longer A-FH distance compared to Class I and III). Authors confirmed that skeletal Classes vary in anterior-posterior and transverse dimensions of the nasopharyngeal airway with Class III having statistically significantly smaller dimension of the nasopharynx. Skeletal Class II patients were described as those having smaller SNB angles, higher ANB and SN-GoGn angles with all of these correlating wit the size of the upper airway. While SNB presents with positive correlation, both ANB and SN-GoGn demonstrate negative correlation with the upper airway dimensions.

In children rapid palatal expansion showed significant improvement in airflow velocity and pressure following intervention [3]. For this purpose effects of different designs of palatal skeletal expanders were compared showing that bone-borne and tooth-bone-borne appliances in adults are equally efficient in increasing the width of the maxillary base contributing to the effects described above. [4].

Screening for the Obstructive Sleep Apnea (OSA) in adults with CBCT is well documented. [5–7] Minimum cross-section area (MCA) of the upper airway is most often used to categorize patients into low (> 110 mm^2) and high risk groups (< 52 mm^2) for developing OSA. The OSA diagnosis is either established with the golden standard OSA testing with Polysomnography (PSG) [7] or via questionnaire screening (STOP-BANG questionnaire [8]) as a risk of developing of OSA.

Despite consistent evidence linking pharyngeal volume and minimum cross-sectional area to obstructive sleep apnea, the contribution of the anterior segment of the upper airway has received comparatively little attention. The nasal passage represents the entry point of the upper airway, and its dimensions may influence airflow characteristics upstream of the collapsible pharyngeal segment. Nasal base width, defined by the vertical plates of the palatine bones at the transition into the nasopharynx, offers a reproducible skeletal landmark for this region, yet it has not been evaluated as a predictor of OSA. The aim of the present study was to determine whether nasal base width is associated with OSA status in adults, independently of the pharyngeal measures emphasized in previous work, and to assess whether the effect of nasal dimension varies with pharyngeal minimum cross-sectional area. We hypothesized that reduced nasal base width would be associated with higher odds of OSA, and that this association would be more pronounced in patients with concurrent pharyngeal narrowing. Sex, age and body mass index were included as covariates. Additional craniofacial and pharyngeal dimensions were examined in exploratory analyses.

Materials and Methods

Study design. This cross-sectional study evaluated the records of 92 adult patients presenting to DrKoval Orthodontics, a private practice limited to orthodontics in Boca Raton, FL, USA. The study was conducted in accordance with the principles of the Declaration of Helsinki, and the study protocol was

reviewed and approved by Solutions Institutional Review Board (Solutions IRB) (approval no. 0846/13 January 2026). Written informed consent was obtained from all participants, and the STROBE reporting guidelines for cross-sectional studies were followed.

Setting. Data were collected at DrKoval Orthodontics, a private practice limited to orthodontics located in Boca Raton, Florida, USA. The practice serves an adult population with a clinical emphasis on airway-focused orthodontic care, and patients are routinely screened for sleep-disordered breathing at initial presentation. Consecutive adult patients presenting between January 2026 and June 2026 who met the eligibility criteria were included. All measurements were derived from cone-beam computed tomography volumes acquired as part of routine diagnostic records at the initial examination appointment, prior to the initiation of any orthodontic treatment. Obstructive sleep apnea status was established by home sleep apnea testing using a seven-channel Zmachine device (General Sleep Corporation, Cleveland, OH, USA). Unlike conventional home sleep apnea tests, which estimate the apnea–hypopnea index using respiratory and oximetric channels against total recording time, the Zmachine incorporates electroencephalographic recording and therefore permits sleep staging and calculation of the apnea–hypopnea index against total sleep time. Studies were scored according to American Academy of Sleep Medicine criteria, and patients with an apnea–hypopnea index of [≥ 5 / ≥15] events per hour were classified as having OSA. OSA severity was quantified using the apnea-hypopnea index (AHI, all apneas plus hypopneas with ≥ 3% oxygen desaturation/hour).

Participants. Consecutive patients who presented for in-person consultation at the practice between January 2026 and June 2026 were assessed for eligibility. Inclusion criteria were age 19 years or older at the time of presentation, availability of a diagnostic cone-beam computed tomography volume obtained as part of routine initial records, and completion of home sleep apnea testing. A total of 101 patients were assessed for eligibility. Two patients were excluded because of a history of bimaxillary orthognathic surgery, two because their imaging records were obtained with an open-mouth posture, and five because home sleep apnea testing did not meet the predefined minimum recording criteria. The final sample comprised 92 patients. (Fig. 1)

Variables. The primary outcome was obstructive sleep apnea status, coded as a binary variable.Nasal base width (NasBase) was measured at the level of the horizontal plate of the palatine bone, immediately anterior to the choanae. Sagittal pharyngeal depth was assessed at two levels, both measured along a perpendicular to the tangent of the posterior pharyngeal wall. PNS-PPW was defined as the shortest distance from the posterior nasal spine to the posterior pharyngeal wall. UPPW was defined as the shortest distance from the uvula to the posterior pharyngeal wall. (Fig. 2).

Upper airway dimensions were assessed using Romexis software (version 6.4.7.129, Planmeca, Helsinki, Finland). The segmented airway was bounded superiorly by a line traced through the ANS–PNS plane and inferiorly by a parallel line through the superior aspect of the epiglottis. Within this volume, the minimum cross-sectional area (MCA) was identified by the software as the smallest cross-sectional area, and upper airway length (UAlength) was defined as the shortest vertical distance between the two

bounding lines. Mandibular rotation was evaluated using the SN-GoMe angle, measured between the sella–nasion plane and the mandibular plane, with larger values indicating greater posterior mandibular rotation. Covariates comprised sex, age at the time of imaging, and body mass index recorded at the initial examination.

Data sources. Measurements. Cone-beam computed tomography volumes were obtained using a Planmeca Viso G7 unit (FOV 20.0 × 20.0 cm, Planmeca, Helsinki, Finland) with an Ultra-Low-Dose (ULD) protocol at 100mV, 5.6 mA, 3.125 sec, and 0.3 mm. Volumes were acquired with the patient in an upright position with natural head posture and without head support, and scans taken with an open-mouth posture were excluded. This approach was chosen deliberately: craniocervical posture, including cervical curvature and head tilt, represents an adaptive response to upper airway dimension rather than an independent source of error, and mechanical restraint would impose a position that does not reflect the patient's habitual airway configuration. Prior to measurement, each volume was oriented within Romexis (version 6.4.7.129, Planmeca, Helsinki, Finland) such that the ANS–PNS plane lay parallel to the true horizontal plane. Nasal base widths, PNS-PPW, UPPW, minimum cross-sectional area and upper airway length were measured directly on the CBCT volumes. Lateral cephalometric radiographs rendered from the same volumes were traced in WebCeph (Seongnam-si, Republic of Korea) for the SN-GoMe angle. All measurements were performed by the Principal Investigator (SK).

Intra-rater reliability was assessed by remeasurement of 20 randomly selected volumes after an interval of two weeks, with the operator blinded to obstructive sleep apnea status and to the original measurements. Intraclass correlation coefficients (two-way mixed effects, absolute agreement, single measurement) and Dahlberg's method error are presented in Table 2. Reliability was excellent for all measures except nasal base width, for which it was good (ICC 0.895). Method error was smallest for the software-derived minimum cross-sectional area, corresponding to approximately 7% of its between-subject standard deviation, and largest in relative terms for nasal base width, at approximately 32%. For PNS-PPW, method error of 0.60 mm corresponded to 16% of the between-subject standard deviation in the study sample, indicating that measurement imprecision was small relative to the variation the analysis sought to detect.

Based on remeasurement of 20 randomly selected volumes after an interval of two weeks. ICC, intraclass correlation coefficient (two-way mixed effects, absolute agreement, single measurement); NasBase, nasal base width; PNS-PPW, posterior nasal spine to posterior pharyngeal wall; UPPW, uvula to posterior pharyngeal wall; MCA, minimum cross-sectional area; UAlength, upper airway length; SN-GoMe, angle between the sella–nasion and mandibular planes. Method error calculated by Dahlberg's formula.

Study size. The sample comprised all consecutive eligible patients presenting during the study period; no a priori sample size calculation was performed, and the sample size was determined by the number of eligible records available. With 49 patients classified as having obstructive sleep apnea, the primary multivariable model containing four predictors corresponded to approximately 12 events per variable, meeting the conventional minimum of ten events per variable for logistic regression. Simulation (2000

replications) indicated that a sample of 92 with the observed outcome prevalence provided 77% power to detect an odds ratio of 1.8 per standard deviation for a single continuous predictor at a two-sided alpha of 0.05, rising to 87% at an odds ratio of 2.0. Power was 46% at an odds ratio of 1.5 and 22% at an odds ratio of 1.3. The study was therefore adequately powered to detect large main effects but underpowered for small to moderate effects, and for interaction terms, which require substantially larger samples to detect at equivalent magnitude. Analyses involving interaction terms or models containing more than five predictors are accordingly reported as exploratory.

Bias. Several potential sources of bias were considered in the design and conduct of this study. Selection bias was mitigated by consecutive enrollment of all eligible patients presenting during the study period. However, the sample was drawn from a single private practice with a clinical emphasis on airway-focused orthodontic care, and patients presenting to this setting are likely to exhibit a higher prevalence of craniofacial and airway characteristics associated with sleep-disordered breathing than the general adult population. This restricts generalizability and may have narrowed the observed range of the craniofacial measurements relative to an unselected population. Measurement bias was addressed through a standardized imaging protocol. All volumes were acquired using identical acquisition parameters, scans obtained with an open-mouth posture were excluded, and each volume was oriented with the ANS–PNS plane parallel to the true horizontal plane prior to measurement. Intra-rater reliability was established by remeasurement of a random subsample after a two-week interval, with the operator blinded to obstructive sleep apnea status and to the original values, and the intraclass correlation coefficient and Dahlberg method error were calculated independently for each variable. All measurements were performed by a single operator, and inter-rater reliability was therefore not assessed. Outcome misclassification was minimized by obtaining two consecutive nights of home sleep apnea testing for each patient. A sleep technician selected the study meeting predefined quality criteria, comprising at least seven hours of recorded sleep and uninterrupted, artifact-free signal across all channels, and a sleep physician interpreted the selected study. The use of electroencephalographic channels permitted calculation of the apnea–hypopnea index against total sleep time rather than total recording time, and the availability of two recordings reduced the influence of night-to-night variability. Residual misclassification would be expected to be non-differential with respect to the craniofacial measurements and would therefore bias associations toward the null. Confounding was addressed by adjustment for sex, age and body mass index, which are established determinants of obstructive sleep apnea risk. Residual confounding from unmeasured factors, including non-anatomical contributors to airway collapse such as ventilatory control stability, arousal threshold and upper airway muscle responsiveness, cannot be excluded. Bias related to the pending patent held by one author (SK) was minimized by blinded data management and independent statistical analysis.

Statistical methods. All analyses were conducted in StataNow/SE 19.5 (StataCorp, College Station, TX, USA). Descriptive statistics summarised the study population, and group characteristics are presented by obstructive sleep apnea status with standardised mean differences. Continuous variables are reported as mean (standard deviation), except body mass index, which departed from normality on the Shapiro–Wilk test and is reported as median (interquartile range). The primary analysis was a

multivariable logistic regression with obstructive sleep apnea status as the dependent variable and nasal base width as the exposure of interest, adjusted a priori for sex, age and body mass index. Odds ratios are reported with 95% confidence intervals, and continuous predictors are additionally reported per standard deviation.

Additional craniofacial and pharyngeal dimensions — minimum cross-sectional area, upper airway length, PNS-PPW, UPPW and the SN-GoMe angle — were examined in exploratory models conducted after the primary hypothesis returned a null result. These analyses were not pre-specified and are reported with uncorrected p-values as hypothesis-generating rather than confirmatory.

Robustness of the principal exploratory finding was assessed by refitting the model with influential observations excluded and by nonparametric bootstrap resampling with 2000 replications. Discrimination was quantified using the area under the receiver operating characteristic curve. A two-sided alpha of 0.05 was used throughout.

Sensitivity analyses examined whether the association between PNS-PPW and obstructive sleep apnea status was altered by adjustment for sagittal (ANB) and vertical (SN-GoMe) skeletal relationship. A multiplicative interaction between PNS-PPW and ANB was additionally fitted with both terms mean-centred, and is reported for completeness; the study was not powered to detect interaction effects.

Results

Participants. Of 101 consecutive adult patients assessed for eligibility, nine were excluded and 92 were analysed (Fig. 1). Forty-nine patients (53.3%) were classified as having obstructive sleep apnea and 43 (46.7%) as not. The sample comprised 57 males and 35 females; OSA was present in 35 of 57 males (61.4%) and 14 of 35 females (40.0%). Baseline characteristics by OSA status are presented in Table 1.

Table 1
Characteristics of the study population by obstructive sleep apnea status.

	OSA_status		
	No OSA	**OSA**	**Total**
N	43 (46.7%)	49 (53.3%)	92 (100.0%)
Age	34.37 (10.60)	37.73 (10.91)	36.16 (10.84)
NasBase	27.51 (2.84)	28.06 (2.96)	27.80 (2.90)
PNS-PPW	25.03 (3.28)	23.39 (3.97)	24.15 (3.73)
U-PPW	7.37 (2.42)	7.05 (2.83)	7.20 (2.64)
MCA	174.37 (65.92)	158.76 (90.18)	166.05 (79.73)
UA length	55.42 (5.64)	58.15 (7.58)	56.88 (6.84)
SN-GoMe	34.53 (8.86)	32.85 (7.76)	33.63 (8.29)
BMI (kg/m²)	23.50 21.60 25.00	26.10 23.90 28.20	24.75 22.65 27.05
Sex			
Female	21 (48.8%)	14 (28.6%)	35 (38.0%)
Male	22 (51.2%)	35 (71.4%)	57 (62.0%)

Values are mean (standard deviation) unless otherwise indicated. Body mass index is presented as median, 25th percentile, and 75th percentile, as it departed from normality on the Shapiro–Wilk test. Categorical variables are presented as n (%). SMD, standardised mean difference; values greater than 0.10 conventionally indicate imbalance between groups.

OSA, obstructive sleep apnea; BMI, body mass index; NasBase, nasal base width at the horizontal plate of the palatine bone; PNS-PPW, shortest perpendicular distance from the posterior nasal spine to the posterior pharyngeal wall; UPPW, shortest perpendicular distance from the uvula to the posterior pharyngeal wall; MCA, minimum cross-sectional area of the segmented upper airway; UAlength, upper airway length; SN-GoMe, angle between the sella–nasion and mandibular planes.

Main results. Nasal base width was not associated with obstructive sleep apnea status. In the multivariable model adjusted for sex, age, body mass index and minimum cross-sectional area, the odds ratio for nasal base width was 1.07 per mm (95% CI 0.91–1.26, p = 0.386), corresponding to 1.23 per standard deviation (95% CI 0.77–1.97). The direction of the point estimate was opposite to that hypothesised. Minimum cross-sectional area was likewise unassociated with OSA status (OR 1.00 per mm², 95% CI 0.99–1.01, p = 0.988). The model as a whole was significant (LR $\chi^2(5) = 16.30$, p = 0.006; pseudo-$R^2 = 0.128$), with body mass index the only individually significant predictor (OR 1.16 per kg/m², 95% CI 1.03–1.31, p = 0.018). Addition of a quadratic term for nasal width did not improve model fit

($\chi^2(1) = 0.25$, $p = 0.620$), and predicted probability of OSA varied by less than 12 percentage points across the full observed range.

Intra-rater reliability was excellent for all measurements except nasal base width, for which it was good (Table 2). Intraclass correlation coefficients ranged from 0.895 for nasal base width to 0.995 for minimum cross-sectional area. Dahlberg's method error was 0.84 mm for nasal base width, 0.60 mm for PNS-PPW, 0.40 mm for UPPW, 1.01 mm for upper airway length, 5.15 mm² for minimum cross-sectional area, and 0.61° for SN-GoMe. Expressed relative to between-subject variation in the study sample, method error was smallest for minimum cross-sectional area at approximately 7% of the standard deviation and largest for nasal base width at approximately 32%; for PNS-PPW it was 16%.

Table 2. Intra-rater reliability of craniofacial and airway measurements.

Variable	ICC (95% CI)	Method error
NasBase	0.895 (0.755–0.957)	0.84 mm
PNS-PPW	0.972 (0.865–0.991)	0.60 mm
UPPW	0.976 (0.940–0.990)	0.40 mm
MCA	0.995 (0.988–0.998)	5.15 mm²
UAlength	0.974 (0.817–0.993)	1.01 mm
SN-GoMe	0.993 (0.978–0.998)	0.61°

Based on remeasurement of 20 randomly selected volumes after an interval of two weeks. ICC, intraclass correlation coefficient (two-way mixed effects, absolute agreement, single measurement); NasBase, nasal base width; PNS-PPW, posterior nasal spine to posterior pharyngeal wall; UPPW, uvula to posterior pharyngeal wall; MCA, minimum cross-sectional area; UAlength, upper airway length; SN-GoMe, angle between the sella–nasion and mandibular planes. Method error calculated by Dahlberg's formula.

Secondary analysis. Of the remaining dimensions examined, only PNS-PPW was associated with OSA status. In a model containing nasal base width, SN-GoMe, upper airway length and PNS-PPW with demographic covariates, PNS-PPW was inversely associated with OSA (OR 0.83 per mm, 95% CI 0.72–0.95, $p = 0.006$), while SN-GoMe (OR 0.97, $p = 0.371$) and upper airway length (OR 1.04, $p = 0.340$) were not. Adding PNS-PPW raised the pseudo-R^2 from 0.128 to 0.206. UPPW, hypothesised to behave similarly, was not associated with OSA status and the point estimate was in the opposite direction (OR 1.13 per mm, 95% CI 0.91–1.42, $p = 0.269$). PNS-PPW and UPPW correlated weakly ($r = 0.40$), while UPPW correlated substantially with minimum cross-sectional area ($\rho = 0.74$) and nasal base width with minimum nasal width ($r = 0.87$).

The PNS-PPW association. In the parsimonious model containing sex, age, body mass index and PNS-PPW (49 events, 12.3 events per variable), each millimeter reduction in PNS-PPW was associated with

higher odds of OSA (OR 0.83, 95% CI 0.72–0.95, p = 0.008), equivalent to an absolute increase in predicted probability of 3.5 percentage points per mm (95% CI 1.3–5.8, p = 0.002). Sex (OR 3.43, 95% CI 1.16–10.14, p = 0.026), body mass index (OR 1.14, 95% CI 1.02–1.29, p = 0.024) and age (OR 1.07 per year, 95% CI 1.02–1.12, p = 0.010) were also associated with OSA status. The model discriminated with an area under the curve of 0.773 (95% CI 0.680–0.866).

Four observations were identified as influential. All four represented patients in whom airway dimension and OSA status were discordant; excluding them strengthened rather than attenuated the association (OR 0.78, 95% CI 0.66–0.91, p = 0.002). Nonparametric bootstrap resampling with 2000 replications produced a percentile confidence interval for the PNS-PPW coefficient that excluded the null (− 0.348 to − 0.070), with a bias of − 0.013.

The association between PNS-PPW and obstructive sleep apnea status was essentially unchanged by adjustment for ANB (OR 0.82, 95% CI 0.71–0.95, p = 0.006) or for SN-GoMe (OR 0.83, 95% CI 0.72–0.95, p = 0.006), and neither skeletal variable was itself associated with OSA status. Across all seven model specifications examined, the odds ratio for PNS-PPW ranged from 0.78 to 0.83 (Table 3). The interaction between PNS-PPW and ANB was not statistically significant (OR 0.97, 95% CI 0.91–1.02, p = 0.211). (Table 3).

Table 3
Multivariable logistic regression for obstructive sleep apnea status, and stability of the PNS-PPW estimate across model specifications.

Predictor	**Odds ratio**	**95% CI**	**p**
Panel A. Primary model (n = 92)			
Sex (male vs female)	3.43	1.16–10.14	0.026
Body mass index (per kg/m²)	1.14	1.02–1.29	0.024
Age (per year)	1.07	1.02–1.12	0.010
PNS-PPW (per mm)	0.83	0.72–0.95	0.008
Panel B. PNS-PPW across model specifications			
Primary model	0.83	0.72–0.95	0.008
Additionally adjusted for ANB	0.82	0.71–0.95	0.006
Additionally adjusted for SN-GoMe	0.83	0.72–0.95	0.006
Additionally adjusted for UPPW	0.80	0.68–0.93	0.005
Full model (7 predictors)	0.83	0.72–0.95	0.006
Model including PNS-PPW × ANB interaction	0.82	0.71–0.95	0.008
Influential observations excluded (n = 88)	0.78	0.66–0.91	0.002

Panel A reports the primary multivariable logistic regression model (likelihood ratio $\chi^2(4) = 23.42$, $p = 0.0001$; pseudo-$R^2 = 0.184$; area under the receiver operating characteristic curve = 0.773, 95% CI 0.680–0.866). Panel B reports the odds ratio for PNS-PPW under alternative covariate sets; all models include sex, body mass index and age. The full model additionally includes nasal base width, SN-GoMe and upper airway length. Female sex is the reference category. Neither ANB (OR 1.13, 95% CI 0.95–1.35, $p = 0.178$) nor SN-GoMe (OR 0.97, 95% CI 0.91–1.03, $p = 0.286$) was associated with obstructive sleep apnea status. In the interaction model both continuous terms were mean-centered; the PNS-PPW × ANB interaction was not statistically significant (OR 0.97, 95% CI 0.91–1.02, $p = 0.211$). The study was not powered to detect interaction effects, and this result should not be interpreted as evidence that the association is uniform across skeletal classes. CI, confidence interval; PNS-PPW, shortest perpendicular distance from the posterior nasal spine to the posterior pharyngeal wall; UPPW, shortest perpendicular distance from the uvula to the posterior pharyngeal wall; SN-GoMe, angle between the Sella–Nasion and mandibular planes.

Discussion

Main findings. In this cross-sectional study of 92 adults, nasal base width was not associated with obstructive sleep apnea (OSA) status. The point estimate was in the opposite direction to that hypothesized (OR 1.07 per mm, 95% CI 0.92–1.26), and no association emerged when a quadratic term was added to test for a non-linear relationship. Minimum cross-sectional area (MCA), the dimension most frequently reported in the upper airway literature, was likewise unassociated with OSA status.

Among the dimensions examined in exploratory analyses, only PNS-PPW discriminated OSA status. Each millimeter of reduction in sagittal nasopharyngeal depth was associated with approximately 20% higher odds of OSA (OR 0.83 per mm increase, 95% CI 0.72–0.95), corresponding to an absolute increase in predicted probability of 3.5 percentage points per millimeter. The association was not attributable to influential observations and survived nonparametric bootstrap resampling.

Sex, age and body mass index behaved as the literature predicts[9]. Male sex was associated with approximately three-fold higher odds of OSA, body mass index with 14% higher odds per kg/m², and age with 7% higher odds per year. The concordance of these estimates with established values indicates that the cohort and outcome ascertainment behaved as expected, and that the null findings for the craniofacial measures are not attributable to a systematically uninformative sample.

Nasal base width. The absence of an association between nasal base width and OSA status does not exclude a role for nasal obstruction in sleep-disordered breathing, but it argues against skeletal nasal width as a useful surrogate for it. Nasal airflow resistance is determined by the nasal valve, septal position, turbinate volume and mucosal state, none of which is captured by a bony dimension measured at the horizontal plate of the palatine bone. Two patients with identical nasal base width may differ substantially in nasal patency. Testing the nasal constriction hypothesis adequately would require functional assessment, such as rhinomanometry or acoustic rhinometry, rather than a skeletal proxy.

Minimum cross-sectional area and head posture. The null result for MCA is better explained by what the measure is sensitive to than by what it represents anatomically. MCA is strongly dependent on craniocervical posture at the moment of acquisition. Coppelson and colleagues demonstrated that the nasion–basion–C3 angle explains more than half the variance in MCA ($R^2 = 0.54$), with ± 5° of angular change corresponding to approximately ± 25% change in MCA and ± 10° to ± 88%[10]. A measure this responsive to head position cannot be interpreted without knowing how position was controlled. Imaging protocols that use chin support or other head restraint impose cervical extension, which inflates MCA artefactually and by a magnitude that exceeds most reported between-group differences. In the present study, volumes were acquired without head or chin restraint, so each patient adopted their natural head posture and MCA was measured without this extension artefact. Efforts to standardize CBCT airway assessment have focused on software workflow and landmark definition, with automated measurement proposed to reduce manual bias [5]; such protocols do not address posture at acquisition.

This has a corollary that bears directly on the present null. If craniocervical posture is itself an adaptive response to airway constraint, patients with compromised airways may adopt compensatory head extension, which would inflate their measured MCA relative to patients without such compensation. Under natural head posture this compensation is captured rather than suppressed, and would reduce rather than exaggerate any difference between groups. The null result for MCA may therefore reflect acquisition conditions in which postural compensation was free to operate. This is relevant to maxillary expansion studies, in which MCA and volumetric change are frequently primary endpoints and acquisition posture is not always specified.

Expressed per standard deviation, the confidence interval for MCA was wide (adjusted OR 0.97, 95% CI 0.60–1.56; Table 4). MCA was measured with [ICC 0.995; method error 5.15 mm^2], so the null is not attributable to measurement imprecision, but an association of moderate magnitude cannot be excluded on these data.

Published comparisons of MCA between patients with and without OSA are inconsistent, and the discrepancies align with differences in acquisition posture. Enciso and colleagues compared adults above and below an apnea–hypopnea index of 10 events per hour and reported significantly smaller MCA in the apneic group, with images acquired supine and the Frankfort plane perpendicular to the floor[11]. Desai and colleagues, combining CBCT with computational fluid dynamics, likewise reported smaller MCA in OSA and showed that the point of greatest constriction corresponded to the point of greatest airflow resistance[12]. In contrast, the meta-analysis by Gurgel and colleagues found no difference in cross-sectional area between patients with and without OSA[13]. In a cohort of 40 men with moderate to severe OSA, Ciavarella and colleagues reported that posterior maxillary width correlated with minimal airway area[14]; that study included no non-apneic comparison group, however, and therefore does not address whether MCA distinguishes patients with OSA from those without.

Sagittal airway dimensions. In contrast to area measures, sagittal dimensions referenced to skeletal landmarks have been consistently reduced in OSA. Gurgel and colleagues found anteroposterior

dimensions reduced in OSA and unaffected by body position at acquisition (Cohen's d = − 0.52), while airway volume was smaller in OSA only when imaged upright (d = − 0.81)[13]. Wei and colleagues reported reduced posterior airway space and pharyngeal airway dimensions in adults with OSA, together with larger ANB angles, shorter mandibular body length and increased lower anterior facial height[15]. The pattern for airway space parallels the present finding: a sagittal dimension discriminated OSA status whereas cross-sectional area did not. The skeletal differences reported by Wei and colleagues, by contrast, were not reproduced here, as neither ANB nor the mandibular plane angle was associated with OSA status.

Not all anteroposterior measures are equivalent. Buchanan and colleagues found no difference in the anteroposterior dimension measured at the site of the MCA, a location that varies between individuals according to where the narrowest point falls[16]. PNS-PPW, by contrast, is anchored to fixed skeletal landmarks and describes the airway at a defined anatomical level. AlAskar and colleagues reported that the most frequent site of constriction lies at the level of the second cervical vertebra, followed by the third[1], well below the plane at which PNS-PPW is measured. The two measures therefore describe anatomically distinct regions, and a null result for one does not bear on the other.

Mechanistic interpretation of PNS-PPW. PNS-PPW is measured at the superior boundary of the segmented pharyngeal airway, at the transition from the rigid nasal passage into the collapsible nasopharynx. Under a Starling resistor model of upper airway collapse, resistance upstream of the collapsible segment lowers intraluminal pressure during inspiration and promotes closure, and a fixed constriction at this transition is a plausible anatomical correlate of that mechanism.

This interpretation is not, however, supported by UPPW, which was measured at the soft palate and would be expected to show a similar association if upstream resistance were driving collapse at the velopharynx. UPPW showed no association with OSA status (adjusted OR 0.97, 95% CI 0.81–1.17). Its point estimate was in the same direction as PNS-PPW but close to unity. UPPW was measured as reliably as PNS-PPW (ICC 0.976; method error 0.40 mm), so its failure to converge cannot be attributed to imprecision. The two measures correlated only weakly (r = 0.40; Supplementary Table S1), indicating that they capture distinct anatomical information, but the absence of convergence means the mechanistic account remains speculative and requires testing in an independent sample.

Nasopharyngeal dimensions vary with sagittal and vertical skeletal pattern[1,2], with the smallest nasopharynx reported in Class III and the smallest MCA in Class II and hyperdivergent patients[2]. This raises the possibility that the PNS-PPW association reflects underlying skeletal relationship rather than airway depth as such. Adjustment for ANB and for the mandibular plane angle left the estimate essentially unchanged; across all adjusted model specifications the odds ratio ranged from 0.78 to 0.83. Neither skeletal variable was itself associated with OSA status (ANB: [OR, 95% CI]; SN-GoMe: Table 4). The association therefore reflects airway depth at the nasopharyngeal transition rather than the skeletal pattern with which that depth covaries.

Discrimination and clinical role. The final model discriminated OSA status moderately well (AUC 0.77; Fig. 3). Adding PNS-PPW to sex, age and body mass index improved discrimination from 0.729 to 0.773 and significantly improved model fit, but PNS-PPW alone discriminated poorly (AUC 0.615). Its value is therefore as a component of anatomical characterization rather than as a standalone screening measure, a role for which it is well suited in orthodontic practice, where CBCT is frequently acquired for other indications. The four influential observations were all patients in whom airway dimension and disease status were discordant. This is consistent with the contribution of non-anatomical factors, such as ventilatory control stability, arousal threshold and upper airway muscle responsiveness, which are not measurable on imaging and are recognized to contribute substantially to the OSA phenotype.

Each dimension was entered into a separate logistic regression model. Adjusted models include sex, age and body mass index (49 events; 12.3 events per variable). Odds ratios below 1.00 indicate higher odds of obstructive sleep apnea with smaller values of the dimension. Odds ratios for minimum cross-sectional area are expressed per mm² and are consequently close to unity; per standard deviation, the adjusted odds ratio was 0.97 (95% CI 0.60–1.56). p-values are uncorrected for multiple comparisons. Only nasal base width was pre-specified; the remaining dimensions were examined in exploratory analyses. CI, confidence interval; OR, odds ratio; PNS-PPW, shortest perpendicular distance from the posterior nasal spine to the posterior pharyngeal wall; UPPW, shortest perpendicular distance from the uvula to the posterior pharyngeal wall; SN-GoMe, angle between the sella–nasion and mandibular planes. (Table 4).

Table 4
Association of each craniofacial and airway dimension with obstructive sleep apnea status, unadjusted and adjusted.

Dimension	Unit	Unadjusted OR (95% CI)	p	Adjusted OR (95% CI)	p
Nasal base width	per mm	1.07 (0.93–1.23)	0.369	1.07 (0.92–1.26)	0.381
PNS-PPW	per mm	0.88 (0.78–0.99)	0.039	0.83 (0.72–0.95)	0.008
UPPW	per mm	0.95 (0.82–1.12)	0.557	0.97 (0.81–1.17)	0.764
Minimum cross-sectional area	per mm²	1.00 (0.99–1.00)	0.348	1.00 (0.99–1.01)	0.898
Upper airway length	per mm	1.06 (1.00–1.14)	0.061	1.04 (0.96–1.12)	0.338
SN-GoMe	per degree	0.98 (0.93–1.03)	0.332	0.97 (0.92–1.03)	0.372

Correlations among all six dimensions are presented in Supplementary Table S1.

Pearson product-moment correlation coefficients. UPPW and minimum cross-sectional area were substantially correlated (r = 0.75), indicating that these measures capture overlapping information; the effective number of independent dimensions examined was therefore smaller than the number of

variables tested. Nasal base width was essentially uncorrelated with the airway dimensions. MCA, minimum cross-sectional area; PNS-PPW, shortest perpendicular distance from the posterior nasal spine to the posterior pharyngeal wall; UPPW, shortest perpendicular distance from the uvula to the posterior pharyngeal wall; SN-GoMe, angle between the sella–nasion and mandibular planes.

Limitations. This study has several limitations. The cross-sectional design precludes any inference about temporality, and reduced nasopharyngeal depth may accompany rather than precede obstructive sleep apnea. The association between PNS-PPW and OSA status emerged from exploratory analyses conducted after the pre-specified hypothesis returned a null result, p-values are uncorrected, and the finding should be regarded as hypothesis-generating pending independent confirmation. The sample was drawn from a single private practice with a clinical emphasis on airway-focused orthodontics, which limits generalizability and may have narrowed the observed range of the craniofacial measurements. The sample size provided adequate power for large main effects but not for interactions, so the absence of an interaction between PNS-PPW and skeletal relationship should not be taken as evidence that the association is uniform across skeletal classes.

Generalizability. The findings apply most directly to adults presenting for orthodontic assessment in a setting where sleep-disordered breathing is routinely screened for and are unlikely to transfer without modification to unselected adult populations or to patients recruited through sleep medicine. The observed prevalence of obstructive sleep apnea in this sample, at 53%, substantially exceeds population estimates and reflects the referral pattern of an airway-focused practice. Measurements were obtained under unrestrained natural head posture, and values derived from protocols employing chin support or standardized head orientation are not directly comparable, particularly for cross-sectional area. Extension of these findings to children and adolescents is not supported, as craniofacial dimensions and the anatomical determinants of upper airway collapse differ in growing patients.

Conclusions

1. Nasal base width, measured at the horizontal plate of the palatine bone, was not associated with obstructive sleep apnea status in adults, and the point estimate lay in the direction opposite to that hypothesized.
2. Minimum cross-sectional area showed no association with obstructive sleep apnea status. As the most reliably measured variable in the study, this null result cannot be attributed to measurement imprecision.
3. Sagittal nasopharyngeal depth at the posterior nasal spine (PNS-PPW) was inversely associated with obstructive sleep apnea status, with each millimeter of reduction corresponding to approximately 21% higher odds and an absolute increase in predicted probability of 3.5 percentage points.

4. This association persisted after adjustment for sagittal and vertical skeletal relationship, was not attributable to influential observations, and remained stable across all model specifications examined.
5. Sex, age and body mass index were associated with obstructive sleep apnea status at magnitudes consistent with published estimates, supporting the internal validity of the cohort.
6. The association between PNS-PPW and obstructive sleep apnea status was identified in exploratory analyses and requires prospective confirmation before it can be regarded as established.

Abbreviations

MARPE	Miniscrew-Assisted Rapid Palatal Expansion
SARPE	Surgically Assisted Rapid Palatal Expansion
RPE	Rapid Palatal Expander
3D-GMP	Three-Dimensional-Guided Midpalatal Piezocorticotomy

Declarations

Human Ethics and Consent to Participate

The study protocol was reviewed and approved by the Solutions Institutional Review Board (Solutions IRB) (Approval No. 0846/01–13/2026). Written informed consent was obtained from all participants.

Consent for publication

Written informed consent for the publication of anonymized data was obtained from all participants prior to enrollment.

Clinical trial number.

Not applicable.

Conflict of Interest.

One author (S.K.) declares a pending patent: US and Canada Patent Pending: Piezocorticotomy guide for midpalatal skeletal expansion (Application # 18/919,416).

Funding.

Not applicable.

Author Contribution

SK worked on the concept of the study, manuscript writing; NS worked on data analysis; AB worj=ked on statistical analysis; DC and MT worked on data collection, tables, and images preparation; AW worked on manuscript conceptualization, review.

Data Availability

The de-identified CBCT measurements and sleep study data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

References

1. AlAskar S, Jamal M, Khamis AH, Ghoneima A. Comparative Assessment of Pharyngeal Airway Dimensions in Skeletal Class I, II, and III Emirati Subjects: A Cone Beam Computed Tomography Study. Dent J. 2024;12(10):301. 10.3390/dj12100301 . PubMed PMID: 39452429; PubMed Central PMCID: PMC11505774.
2. Al-Somairi MAA, Liu Y, Almashraq AA, Almaqrami BS, Alshoaibi LH, Alyafrusee ES, et al. Correlation between the three-dimensional maxillomandibular complex parameters and pharyngeal airway dimensions in different sagittal and vertical malocclusions. Dento Maxillo Facial Radiol. 2023;52(3):20220346. 10.1259/dmfr.20220346 . PubMed PMID: 36695712; PubMed Central PMCID: PMC9944012.
3. Lo Giudice A, Polizzi A, Lagravere M, Flores-Mir C, Isola G, Ronsivalle V, et al. Changes in upper airway airflow after rapid maxillary expansion considering normal craniofacial development as a factor: a retrospective study using computer fluid dynamics. Eur J Orthod. 2024;47(1):cjae077. 10.1093/ejo/cjae. 077 PubMed PMID: 39764702.
4. Demirsoy KK, Buyuk SK, Alev Y, Bicer T, Abay F. Comparative Evaluation of Skeletal, Dentoalveolar, and Airway Effects of Bone-Borne and Hybrid Expanders in Young Adults. Orthod Craniofac Res. 2025 Dec;30. 10.1111/ocr.70091 . PubMed PMID: 41472450.
5. Fonseca C, Cavadas F, Fonseca P. Upper Airway Assessment in Cone-Beam Computed Tomography for Screening of Obstructive Sleep Apnea Syndrome: Development of an Evaluation Protocol in Dentistry. JMIR Res Protoc. 2023;12:e41049. doi:10.2196/41049 PubMed PMID: 37145857; PubMed Central PMCID: PMC10199385.
6. Chousangsuntorn K, Bhongmakapat T, Apirakkittikul N, Sungkarat W, Supakul N, Laothamatas J. Upper Airway Areas, Volumes, and Linear Measurements Determined on Computed Tomography During Different Phases of Respiration Predict the Presence of Severe Obstructive Sleep Apnea. J

Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2018;76(7):1524–31. .041 PubMed PMID: 29289684.

7. Jessadapornchai T, Samruajbenjakun B, Chanmanee P, Chalidapongse P. 3D analysis of upper airway morphology related to obstructive sleep apnea severity. J World Fed Orthod. 2024;13(4):175–80. 10.1016/j.ejwf.2024.03.003 . PubMed PMID: 38688739.
8. Eow PY, Lin KY, Kohli S, Math SY. Cone-beam computed tomography assessment of upper airway dimensions in patients at risk of obstructive sleep apnea identified using STOP-Bang scores. Imaging Sci Dent. 2021;51(4):439–46. 10.5624/isd.20210193 . PubMed PMID: 34988005; PubMed Central PMCID: PMC8695467.
9. Esmaeili N, Gell L, Imler T, Hajipour M, Taranto-Montemurro L, Messineo L, et al. The relationship between obesity and obstructive sleep apnea in four community-based cohorts: an individual participant data meta-analysis of 12,860 adults. EClinicalMedicine. 2025;83:103221. 10.1016/j.eclinm.2025.103221 . PubMed PMID: 40330547; PubMed Central PMCID: PMC12051718.
10. Coppelson K, Summersgill I, Hatcher D, Nguyen G, Pada H, Stewart H, et al. J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg. 2023;81(6):721–33. 10.1016/j.joms.2023.01. .016 PubMed PMID: 36841260. Does Head and Neck Posture Affect Cone-Beam Computed Tomography Assessment of the Upper Airway?.
11. Enciso R, Nguyen M, Shigeta Y, Ogawa T, Clark GT. Comparison of cone-beam CT parameters and sleep questionnaires in sleep apnea patients and control subjects. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;109(2):285–93. 10.1016/j.tripleo.2009.09.033 . PubMed PMID: 20123412; PubMed Central PMCID: PMC2900776.
12. Desai R, Komperda J, Elnagar MH, Viana G, Galang-Boquiren MTS. Evaluation of upper airway characteristics in patients with and without sleep apnea using cone-beam computed tomography and computational fluid dynamics. Orthod Craniofac Res. 2023;26(Suppl 1):164–70. 10.1111/ocr.12728 . PubMed PMID: 38009653.
13. Gurgel ML, Junior CC, Cevidanes LHS, de Barros Silva PG, Carvalho FSR, Kurita LM, et al. Methodological parameters for upper airway assessment by cone-beam computed tomography in adults with obstructive sleep apnea: a systematic review of the literature and meta-analysis. Sleep Breath Schlaf Atm. 2023;27(1):1–30. 10.1007/s11325-022-02582-6 . PubMed PMID: 35190957; PubMed Central PMCID: PMC9392812.
14. Ciavarella D, Ferrara D, Spinoso G, Cattaneo P, Leo C, Russo LL, et al. Airway Analysis and Morphometric Assessment of Dental Arches in Obstructive Sleep Apnea Patients. J Clin Med. 2025;14(2):296. 10.3390/jcm14020296 . PubMed PMID: 39860302; PubMed Central PMCID: PMC11766405.
15. Wei Z, Zhao T, Li Y, Ngan P, Wang Z, Hua F, et al. The dentofacial and upper airway morphology of adults with obstructive sleep apnea: A systematic review and meta-analysis. Sleep Med Rev. 2025;80:102065. 10.1016/j.smrv.2025.102065 . PubMed PMID: 39899914.

16. Buchanan A, Cohen R, Looney S, Kalathingal S, De Rossi S. Cone-beam CT analysis of patients with obstructive sleep apnea compared to normal controls. Imaging Sci Dent. 2016;46(1):9–16. 10.5624/isd.2016.46.1.9 . PubMed PMID: 27051634; PubMed Central PMCID: PMC4816775.

Figures

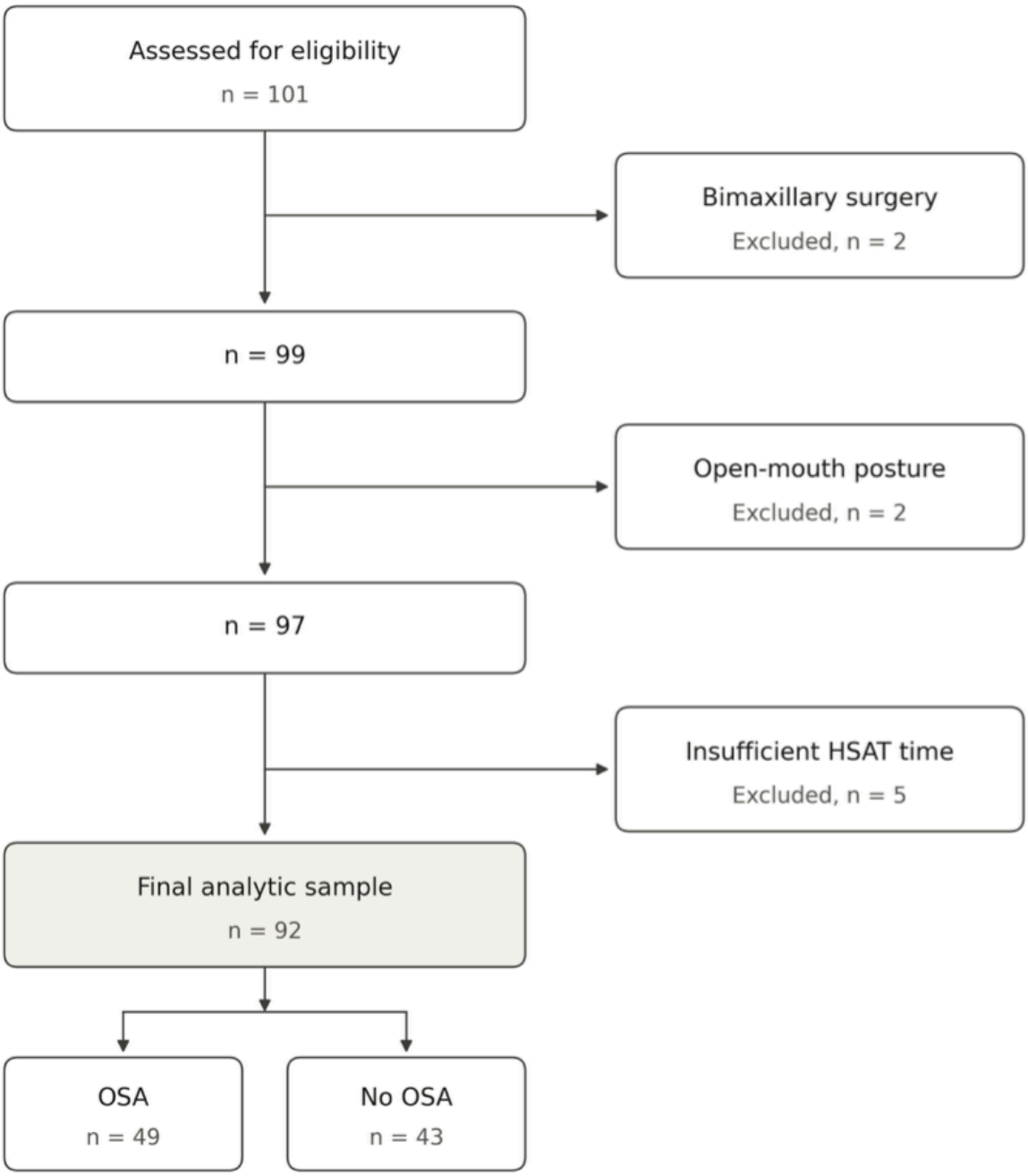


Figure 1

Participant flow. Of 101 consecutive adult patients assessed for eligibility between January 2024 and June 2026, two were excluded for a history of bimaxillary orthognathic surgery, two for imaging records obtained with an open-mouth posture, and five for home sleep apnea testing (HSAT) that did not meet the predefined minimum recording criteria. The final analytic sample comprised 92 patients, of whom 49 were classified as having obstructive sleep apnea and 43 as not.

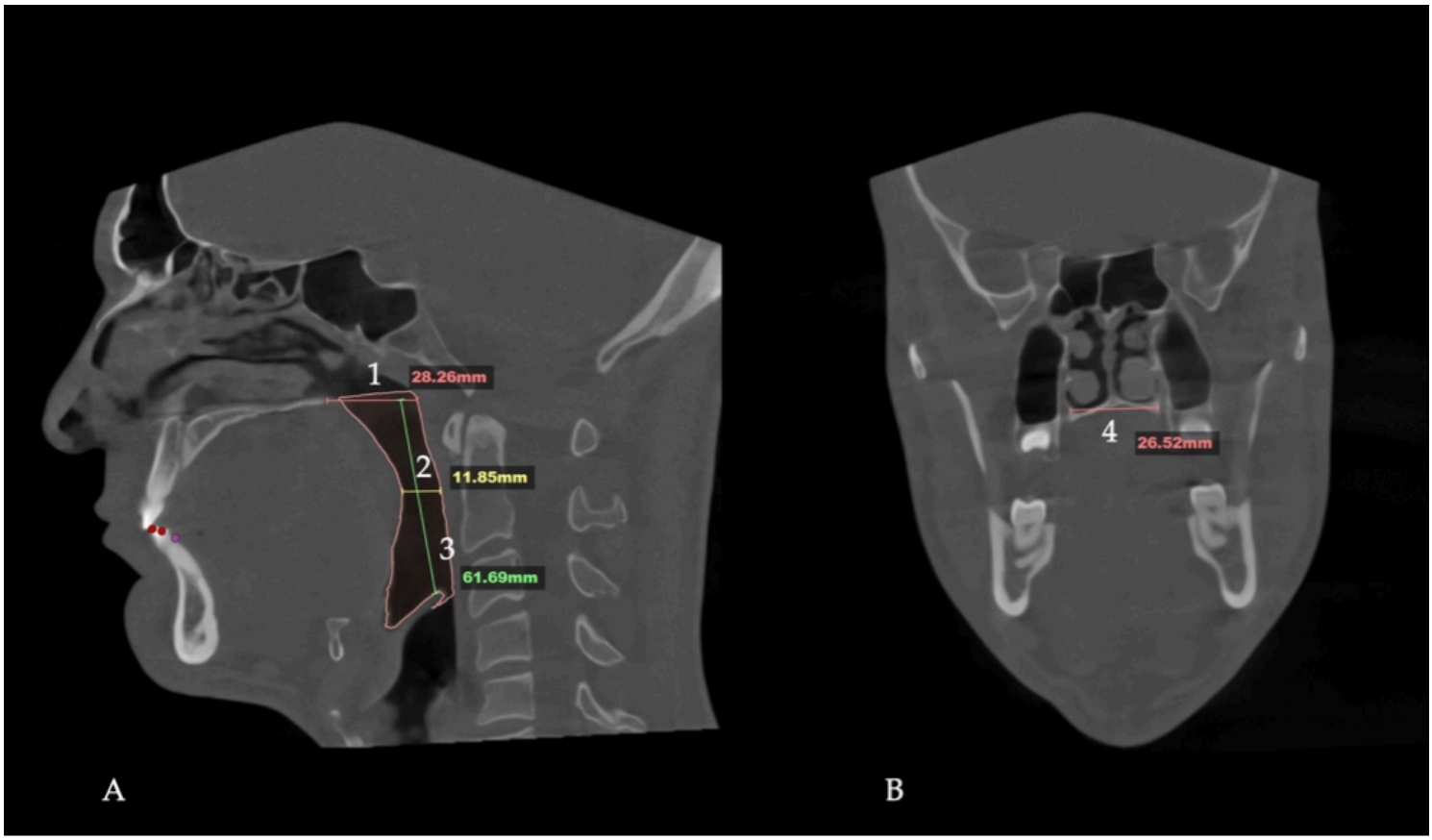


Figure 2

CBCT measurement of upper-airway and nasal-base dimensions. (A) Midsagittal CBCT slice showing the segmented upper airway (outlined) and linear measurements: (1) PNS-PPW, the distance from posterior nasal spine (PNS) to the posterior pharyngeal wall along the palatal plane; (2) UPPW, Uvula – to - Posterior Pharyngeal Wall distance, mm; (3) UA length, upper-airway length measured along the airway midline from the palatal plane to the superior pole of the epiglottis. (B) Coronal CBCT slice showing (4) NasBase, the nasal base width measured at the level of the horizontal plate of the palatine bone. Values shown are from a representative patient (1: 28.26 mm; 2: 11.85 mm; 3: 61.69 mm; 4: 26.52 mm). CBCT, cone-beam computed tomography; PNS, posterior nasal spine; PPW, posterior pharyngeal wall; UA, upper airway.

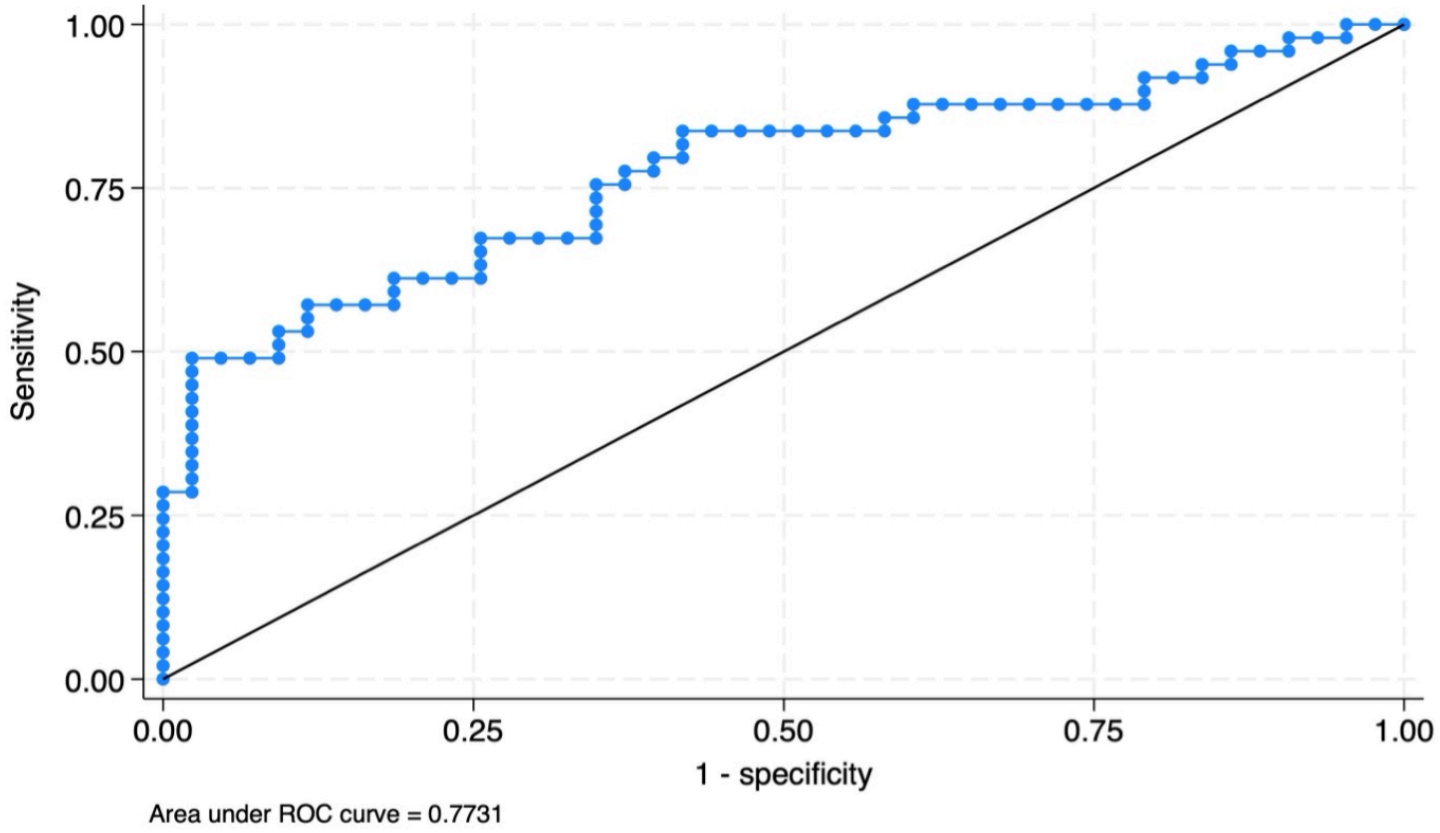


Figure 3

Receiver operating characteristic curves for obstructive sleep apnea status (n = 92). Curves are shown for a model containing sex, age and body mass index (AUC 0.729), the same model with PNS-PPW added (AUC 0.773), and PNS-PPW alone (AUC 0.615). Addition of PNS-PPW significantly improved model fit (likelihood ratio $\chi^2(1) = 7.89$, $p = 0.005$). The diagonal reference line indicates discrimination equivalent to chance.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTableS1.docx