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PAPER

Multifactorial assessment of halitosis in systemically and orally healthy orthodontic patients: airway dimensions, breathing pattern, and comparison with a portable breath analyzer

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Keywords: halitosis, airway dimensions, cephalometric analysis, mouth breathing, portable breath analyzer, orthodontics

Abstract

Halitosis is a multifactorial condition influenced by airway-related factors and breathing patterns. This study aimed to evaluate the relationship between airway dimensions, craniofacial morphology, and breathing type with halitosis in orthodontic patients. In addition, the agreement between the portable breath analyzer and the organoleptic method, as well as the role of self-reported and physiological halitosis, was investigated. This cross-sectional study included 113 systemically and orally healthy orthodontic patients. Lateral cephalometric radiographs were used to assess the sagittal and vertical skeletal patterns and pharyngeal airway dimensions. Halitosis was evaluated using an organoleptic method as the reference standard and a portable breath analysis device for comparison. Oral hygiene habits, breathing type, and perception of halitosis were recorded using a structured questionnaire. Statistical analyses included appropriate parametric and nonparametric tests as well as multivariate logistic regression. Agreement was assessed using Cohen's kappa coefficient. The overall prevalence of halitosis was 8.9% based on organoleptic assessment. Tooth brushing frequency ($p = 0.041$) and oral dryness ($p = 0.004$) were significantly associated with halitosis, whereas airway dimensions, skeletal patterns, and breathing types were not ($p > 0.05$). Physiological halitosis ($p = 0.003$) and oral dryness ($p = 0.047$) were significant predictors of self-reported halitosis. The agreement between the self-reported and objective measurements was weak ($\kappa = 0.264$; $p < 0.001$). A statistically significant and substantial level of agreement was observed between the portable device and the organoleptic assessment ($\kappa = 0.698$). Airway-related parameters were not identified as significant determinants of halitosis. Within the limitations of this study, halitosis was more closely associated with self-reported oral dryness and tooth-brushing frequency than with airway morphology. Portable breath analyzers may serve as practical adjunctive tools for clinical assessments when used under standardized conditions.

1. Introduction

Halitosis, defined as an unpleasant odor originating from the oral cavity, is a multifactorial condition that negatively affects social and psychological wellbeing [1]. Intraoral factors account for approximately 85%–90% of cases, most commonly tongue coating, periodontal disease, and reduced salivary flow, whereas extraoral factors such as nasopharyngeal infections, sinusitis, and certain systemic conditions may also contribute to its etiology [2, 3]. According to the International Association for Halitosis Research, halitosis is among the most common reasons for seeking dental consultations worldwide [4].

Recent studies have highlighted the roles of salivary flow and airway-related factors in the development of halitosis. In particular, mouth breathing has been associated with decreased salivary flow and increased oral microbial activity due to dehydration of mucosal surfaces [5, 6]. Craniofacial morphology and airway dimensions influence breathing patterns and airway patency, which may indirectly affect the

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oral microenvironment. Reduced airway space may promote mouth breathing and increased oral dryness, potentially facilitating the development of halitosis [7].

Although numerous studies have focused on the intraoral causes of halitosis, research examining their association with craniofacial morphology, airway dimensions, and breathing patterns, especially in orthodontic populations, remains limited. Craniofacial skeletal characteristics and pharyngeal airway anatomy have been shown to influence respiratory patterns and airway patency [7, 8]. However, evidence regarding the relationship between sagittal and vertical skeletal patterns, airway dimensions, mouth breathing, and halitosis is inconsistent and inconclusive [8–10]. Therefore, evaluating these factors within a multifactorial framework may provide a more comprehensive understanding of halitosis [2, 3].

Orthodontic patients represent a particularly relevant population for investigating these relationships because craniofacial morphology, skeletal discrepancies, and airway characteristics are routinely assessed during orthodontic diagnosis and treatment planning. Airway assessment has become an increasingly important component of contemporary orthodontic practice because alterations in airway morphology and respiratory function may influence craniofacial growth, facial pattern development, and treatment outcomes [9, 11]. Recent studies have further demonstrated that sagittal and vertical skeletal discrepancies may be associated with variations in pharyngeal airway dimensions, emphasizing the importance of airway evaluation in orthodontic patients [9, 11]. Furthermore, routine orthodontic records commonly include lateral cephalometric radiographs, providing a practical opportunity to investigate potential associations between airway-related factors, breathing patterns, and halitosis. Therefore, a better understanding of these interactions may contribute to a more comprehensive assessment of orthodontic patients and support interdisciplinary approaches in clinical practice.

The clinical assessment of halitosis also presents methodological challenges. Although the organoleptic method remains widely accepted as the clinical reference standard, its subjective nature and examiner dependency may limit its reproducibility [12]. Device-based measurements of volatile sulfur compounds (VSCs) provide quantitative data; however, in routine clinical practice, portable breath analysis devices are generally used as complementary tools to support organoleptic assessment, rather than standalone diagnostic methods [13, 14].

In this context, it is important to consider not only objective measurements but also patients' subjective perceptions and daily observations of breath odor patterns in the evaluation of halitosis. In particular, breath odor that occurs in the morning and resolves within a short period is defined as physiological halitosis and should be distinguished from pathological halitosis [3, 15]. However, the agreement between self-reported halitosis and objective measurements is known to be limited [12, 16]. Therefore, combining subjective and objective assessments may provide a more comprehensive understanding of halitosis.

Accordingly, this study aimed to evaluate the relationship between airway dimensions associated with sagittal and vertical skeletal patterns, mouth breathing, and the presence of halitosis in individuals scheduled for orthodontic treatment within a multifactorial framework. In addition, the associations between self-reported halitosis and physiological halitosis patterns and these variables were investigated. A portable breath analysis device was used as an adjunct tool to support organoleptic assessments.

Accordingly, the hypotheses of the study are as follows:

H_0 (null hypothesis): There is no association between sagittal and vertical craniofacial patterns, pharyngeal airway dimensions, or breathing pattern (nasal versus mouth breathing) and the presence or severity of halitosis in individuals prior to orthodontic treatment. H_1 (alternative hypothesis): Sagittal and/or vertical craniofacial patterns, pharyngeal airway dimensions, and breathing pattern (nasal versus mouth breathing) are associated with the presence and severity of halitosis in individuals prior to orthodontic treatment.

2. Materials and methods

2.1. Study design, ethical approval and safety considerations

This observational cross-sectional study was conducted at the Department of Orthodontics and the Department of Oral and Maxillofacial Radiology, Uşak University Faculty of Dentistry. Ethical approval was obtained from the Uşak University Non-Interventional Clinical Research Ethics Committee (Approval No: 216-216-18, dated 12 October 2023), and all procedures were performed in accordance with the principles of the Declaration of Helsinki.

The study utilized pretreatment lateral cephalometric radiographs obtained as part of routine orthodontic records, together with prospectively collected halitosis measurements and questionnaire data. All procedures were conducted in accordance with standard infection control protocols. During breath sample collection, appropriate personal protective equipment was used, and disposable mouthpieces were employed for each participant. The portable breath analyzer was operated according to the manufacturer's instructions, and all contact surfaces were disinfected after each use. Breath sampling was performed in a well-ventilated clinical environment, and no hazardous chemicals were involved in

the analysis. All potentially contaminated materials were disposed of in accordance with medical waste regulations, ensuring the safety of both participants and personnel.

2.2. Participants

Sample size calculations were performed using the *G*Power software (version 3.1; Heinrich Heine University, Düsseldorf, Germany). Based on a medium effect size ($f = 0.30$), type I error rate of 5% ($\alpha = 0.05$), and statistical power of 80% ($\beta = 0.20$), a minimum sample size of 111 participants was required for one-way ANOVA. The sample size calculation was performed for group comparisons using one-way ANOVA and was not specifically designed for logistic regression modeling.

In total, 130 patients were initially assessed for eligibility. Seventeen patients were excluded according to the predefined criteria, and the final study sample consisted of 113 participants.

Inclusion criteria

- Patients seeking orthodontic treatment
- Availability of pretreatment lateral cephalometric radiographs

Exclusion criteria

- Refusal to participate
- Presence of congenital or acquired craniofacial anomalies
- History of systemic disease or regular medication use
- Poor-quality or missing lateral cephalometric radiographs
- Presence of active dental caries, poor oral hygiene, or periodontal disease that could contribute to intraoral halitosis.

Participant classification

The participants were categorized by age, sex, skeletal pattern (sagittal and vertical), and breathing type, as follows:

- **Age groups:** 7–12 years, 13–18 years, and $\geqslant$19 years
- **Sagittal skeletal pattern:** Based on ANB angle: Class I ($0° \leqslant$ ANB $\leqslant 4°$), Class II (ANB $> 4°$), and Class III (ANB $< 0°$)
- **Vertical skeletal pattern:** Based on SN/GoGn angle: hyperdivergent (SN/GoGn $> 36°$), normodivergent ($26° <$ SN/GoGn $< 36°$), and hypodivergent (SN/GoGn $< 26°$)
- **Breathing pattern:** Determined by questionnaire as nasal or oral breathers

To minimize the influence of major intraoral and systemic factors known to contribute to halitosis, individuals with active dental caries, periodontal disease, poor oral hygiene, systemic diseases, or regular medication use were excluded. Consequently, the study population represented a relatively homogeneous group of systemically and orally healthy orthodontic patients.

2.3. Data collection and measurements

2.3.1. Cephalometric analysis

All lateral cephalometric radiographs were obtained under standardized conditions using the Vatech Digital x-ray Imaging System PCH-2500 (Vatech, Seoul, Korea). During image acquisition, the patients were positioned with the Frankfurt horizontal plane parallel to the floor and their teeth in centric occlusion. The exposure parameters were set to 72 kVp, 10 mA, and 8 s.

Cephalometric measurements were performed using the Dolphin Imaging software (version 11.95 premium; Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). Prior to analysis, each radiograph was digitally calibrated using a 5-mm reference ruler.

The superior posterior airway space (SPAS) was measured using McNamara airway analysis in Dolphin Imaging Software. The measurement was performed using the posterior upper, posterior lower, anterior upper, and anterior lower reference points predefined by the software. The landmarks used for SPAS measurement are illustrated in figure 1. Airway width was categorized according to the normative SPAS reference value (13 mm) provided by Dolphin Imaging Software. SPAS values below 13 mm were classified as reduced airway width, whereas values of 13 mm or greater were classified as normal airway width.

To assess intra-examiner reliability, 20 randomly selected cephalograms were remeasured by the same examiner two weeks after the initial assessment in a blinded manner. Intraclass correlation coefficient analysis demonstrated excellent agreement between the first and second measurements (ICC = 0.981).

2.4. Halitosis assessment

Halitosis was evaluated using two complementary methods:

1. **Organoleptic assessment:** Organoleptic evaluation was performed by a single examiner trained and calibrated in halitosis assessment procedures. Prior to the study, the examiner underwent calibration training using standardized organoleptic assessment procedures. To ensure standardization and to reduce examiner-related bias, all evaluations followed a predefined protocol. Both the examiner and participants were instructed to refrain from smoking, consuming coffee or alcohol, using

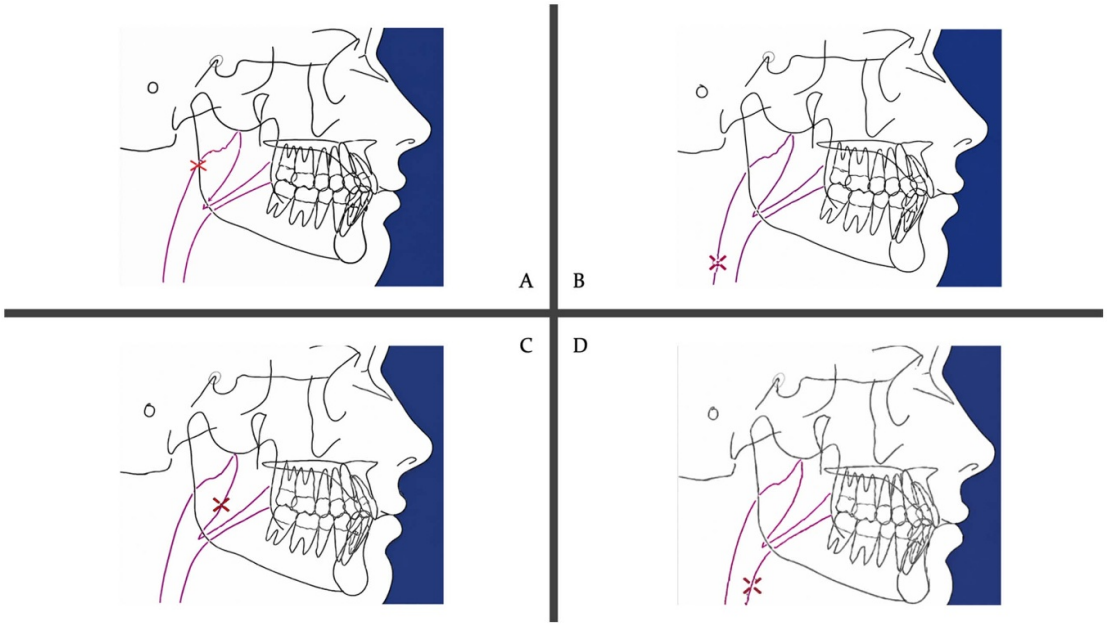


Figure 1. Reference points used for superior posterior airway space (SPAS) measurement according to McNamara airway analysis in Dolphin Imaging Software. (A) posterior upper, (B) posterior lower, (C) anterior upper, and (D) anterior lower reference points.

perfume or scented personal care products, and ingesting strongly odoriferous foods, such as garlic or onions, prior to assessment. Organoleptic scoring was performed using the Rosenberg scale under controlled clinical conditions, with participants seated upright and breathing normally during the evaluation [17]. Organoleptic scores of $\geqslant 2$ were considered indicative of halitosis. Two measurements were performed 10 min apart, and the mean score was recorded. The examiner was blinded to the questionnaire responses, cephalometric findings, and portable breath analyzer results during organoleptic assessment.

2. **Portable breath analysis device:** Portable breath analysis was performed using the YRY Smart Breath Odor Detector (YRY, Shenzhen, China) according to the manufacturer's instructions. The device utilizes a microelectromechanical system sensor designed to detect VSCs associated with oral malodor and automatically calibrates before each measurement. To reduce the potential influence of measurement variability, two readings were obtained 10 min apart, and the mean score was recorded for statistical analyses. According to the manufacturer's scoring system, a score of 0 indicates no detectable odor, 1 indicates acceptable breath odor, 2 indicates mild halitosis, 3 indicates moderate halitosis, and 4 indicates severe halitosis. Therefore, scores of $\geqslant 2$ were considered indicative of halitosis. All measurements were performed in accordance with the manufacturer's instructions and under standardized clinical conditions.

The portable breath analyzer was used as an adjunctive semi-quantitative tool and was not considered a standalone diagnostic reference method. Organoleptic assessment was accepted as the clinical reference standard.

As the device provides semi-quantitative ordinal scores rather than direct quantitative VSC concentrations, its results were interpreted only as adjunctive screening data. The detection range and analytical repeatability values were not independently verified in the present study.

Both assessment methods were conducted according to the following standardized protocol: All measurements were performed in the morning, participants avoided antibiotic use for at least three weeks prior to testing, consumption of foods and beverages with strong odors was restricted for 48 h before assessment, and eating or drinking (except water) was prohibited within two hours before evaluation.

2.5. Questionnaire evaluation

A structured questionnaire adapted from the Halitosis-Associated Life-Quality Test and Halifins surveys [18, 19] was used to evaluate oral hygiene habits and breathing type. The original English items were translated into Turkish, following the cross-cultural adaptation protocol proposed by Beaton *et al* [20]. The final version was reviewed by two independent researchers to ensure conceptual equivalence and linguistic accuracy.

In addition, self-reported halitosis and physiological halitosis patterns were evaluated based on the

questionnaire responses. Physiological halitosis was defined as the presence of breath odor in the morning that resolves within a short period of time following oral hygiene practices or food and beverage intake [15]. On the basis of these criteria, physiological halitosis was categorized as a binary variable (present/absent). Breathing pattern was determined based on self-reported questionnaire responses and was not confirmed by objective clinical or otorhinolaryngological assessment.

2.6. Statistical analysis

Descriptive statistics (frequencies, percentages, means, standard deviations, and ranges) were calculated. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using the Levene test. Depending on the data distribution, parametric comparisons were performed using ANOVA, whereas nonparametric comparisons were conducted using the Kruskal–Wallis test. Categorical variables were analyzed using Fisher's exact test, and post hoc analyses were performed using Dunn–Bonferroni correction.

Multivariate logistic regression analysis was performed to identify factors associated with self-reported halitosis. In this model, self-reported halitosis was defined as the dependent variable, whereas age, sex, sagittal and vertical skeletal patterns, airway width, oral dryness, mouth-breathing, and physiological halitosis were included as independent variables. Odds ratios (ORs) and 95% confidence intervals (CIs) were also calculated. Model fit was assessed using the Hosmer–Lemeshow test, and explanatory power was summarized using Nagelkerke R^2. Multicollinearity among independent variables was evaluated using variance inflation factors, and no significant multicollinearity was detected.

A separate multivariate logistic regression model was constructed for the physiological halitosis. In this model, physiological halitosis was defined as the dependent variable, whereas oral dryness, mouth breathing, sagittal and vertical skeletal patterns, and airway dimensions were included as independent variables.

All analyses were conducted using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA) with the level of significance set at $p < 0.05$. Agreement between subjective and objective measurements was evaluated using Cohen's kappa coefficient [21].

3. Results

A total of 113 participants were included in this study. The majority were aged 13–18 years (61.1%), followed by those aged ⩾19 years (21.2%), and ⩽12 years (17.7%). The sample consisted of 53.1% females and 46.9% males (table 1).

Table 1. Distribution of participants according to demographic and personal characteristics.

Variable	Category	*n*	%
Age	⩽12 years	20	17.7
	13–18 years	69	61.1
	⩾19 years	24	21.2
Gender	Female	60	53.1
	Male	53	46.9

The overall prevalence of halitosis was 8.9%, based on organoleptic assessment.

Analysis of questionnaire-based variables demonstrated that tooth brushing frequency ($p = 0.041$) and oral dryness ($p = 0.004$) were significantly associated with halitosis scores. In contrast, dental floss ($p = 0.244$), mouthwash ($p = 0.592$), tongue cleaner ($p = 0.909$), mouth breathing ($p = 0.177$), and lip dryness ($p = 0.703$) were not significantly associated with halitosis (table 2).

Airway width measurements did not differ significantly among the sagittal skeletal pattern groups (p = 0.333) or among the vertical skeletal pattern groups (p = 0.369). The mean airway width was 13.08 ± 3.43 mm in Class I, 11.66 ± 3.63 mm in Class II, and 12.64 ± 4.15 mm in Class III participants. According to vertical skeletal pattern, the mean airway width was 12.92 ± 3.89 mm in normodivergent, 11.80 ± 3.77 mm in hypodivergent, and 12.13 ± 3.25 mm in hyperdivergent participants (table 3).

Multivariate logistic regression analysis identified physiological halitosis and oral dryness as the significant predictors of self-reported halitosis. Individuals with physiological halitosis had significantly higher odds of reporting halitosis (OR = 11.565; 95% CI, 2.286–58.513; $p = 0.003$). Similarly, oral dryness was associated with an increased likelihood of self-reported halitosis (OR ratio, 2.857; 95% CI, 1.015–8.043; $p = 0.047$). In addition, the Class III skeletal pattern was identified as a significant predictor in the multivariate model ($p = 0.015$).

In contrast, mouth breathing, Class II sagittal skeletal pattern, hyperdivergent and hypodivergent vertical skeletal patterns, airway width categories, ANB angle, SN–GoGn angle, and airway width (mm) were not significantly associated with self-reported halitosis (table 4).

Agreement analysis demonstrated a statistically significant but weak level of agreement between self-reported and clinical halitosis ($\kappa = 0.264$; $p < 0.001$). Self-reported halitosis showed high sensitivity (90.0%) and specificity (70.9%), with a low positive predictive value (23.1%) and high negative predictive value (98.6%), resulting in an overall classification accuracy of 72.6%.

For physiological halitosis, no significant agreement was observed with clinical halitosis ($\kappa = 0.059$; $p = 0.063$). Although the sensitivity was high

Table 2. Association between questionnaire-based variables and halitosis scores.

		0			1			2			3			
		n	%	%*H.*	*n*	%	%*H.*	*n*	%	%H.	*n*	%	%*H.*	*p*
How often do you brush your teeth?	Twice a day	17	29.3	50.0	38	65.5	55.1	2	3.4	25.0	1	1.7	50.0	**.041***
	Once a day	15	37.5	44.1	19	47.5	27.5	6	15.0	75.0	0	0.0	0.0	
	Every 2–3 d	1	9.1	2.9	10	90.9	14.5	0	0.0	0.0	0	0.0	0.0	
	Less frequently	1	25.0	2.9	2	50.0	2.9	0	0.0	0.0	1	25.0	50.0	
Do you use dental floss regularly?	Yes	3	16.7	8.8	13	72.2	18.8	1	5.6	12.5	1	5.6	50.0	.244
	No	31	32.6	91.2	56	58.9	81.2	7	7.4	87.5	1	1.1	50.0	
How often do you use mouthwash?	Daily	7	46.7	20.6	8	53.3	11.6	0	0.0	0.0	0	0.0	0.0	.592
	Every 2–3 d	1	25.0	2.9	2	50.0	2.9	1	25.0	12.5	0	0.0	0.0	
	Once a week	1	14.3	2.9	6	85.7	8.7	0	0.0	0.0	0	0.0	0.0	
	I do not use mouthwash	25	28.7	73.5	53	60.9	76.8	7	8.0	87.5	2	2.3	100.0	
How often do you use a tongue cleaner?	Daily	8	29.6	23.5	17	63.0	24.6	2	7.4	25.0	0	0.0	0.0	.909
	Every 2–3 d	3	20.0	8.8	11	73.3	15.9	1	6.7	12.5	0	0.0	0.0	
	Once a week	2	33.3	5.9	3	50.0	4.3	1	16.7	12.5	0	0.0	0.0	
	I do not use a tongue cleaner	21	32.3	61.8	38	58.5	55.1	4	6.2	50.0	2	3.1	100.0	
Do you breathe through your mouth?	Yes	17	41.5	50.0	21	51.2	30.4	3	7.3	37.5	0	0.0	0.0	.177
	No	17	23.6	50.0	48	66.7	69.6	5	6.9	62.5	2	2.8	100.0	
Do you experience oral dryness?	Yes	8	21.6	23.5	22	59.5	31.9	7	18.9	87.5	0	0.0	0.0	**.004***
	No	26	34.2	76.5	47	61.8	68.1	1	1.3	12.5	2	2.6	100.0	
Do your lips feel dry?	Yes	18	28.1	52.9	40	62.5	58.0	4	6.3	50.0	2	3.1	100.0	.703
	No	16	32.7	47.1	29	59.2	42.0	4	8.2	50.0	0	0.0	0.0	

p-values were calculated using Fisher's exact test.
%*H*: Percentage within halitosis score category.

Table 3. Distribution and comparison of airway width measurements according to sagittal and vertical skeletal pattern classifications.

		Min–Max	Mean ± SD (Median)	*p*
Sagittal skeletal pattern	Class I	7,9–22,3	13,08 ± 3,43(12,5)	.333
	Class II	3,8–19,2	11,66 ± 3,63(11,3)	
	Class III	5,5–20,5	12,64 ± 4,15(12,4)	
Vertical skeletal pattern	Normodivergent	3,8–22,3	12,92 ± 3,89(12,4)	.369
	Hypodivergent	5,7–20,5	11,8 ± 3,77(11,7)	
	Hyperdivergent	6,1–17,6	12,13 ± 3,25(12,3)	

Comparisons were performed using ANOVA or Kruskal–Wallis tests.

(100.0%), the specificity (26.2%) and overall classification accuracy (32.7%) were low, indicating limited diagnostic performance (table 5).

Agreement analysis demonstrated a substantial level of agreement between the portable breath analyzer and organoleptic assessment ($\kappa = 0.698$; $p < 0.001$). The device showed a sensitivity of 80.0%, specificity of 96.1%, positive predictive value of 66.7%, negative predictive value of 98.0%, and an overall diagnostic accuracy of 94.7% (table 6).

4. Discussion

This observational cross-sectional study evaluated the relationship between airway dimensions, sagittal and vertical skeletal patterns, breathing patterns, and halitosis in individuals scheduled for orthodontic treatment. In addition, the agreement between the portable breath analysis device and the organoleptic method was examined. The findings demonstrated a statistically significant and substantial level of agreement between the portable breath analysis device and the organoleptic method. Furthermore, no significant associations were detected between airway dimensions, craniofacial skeletal patterns, breathing patterns, and halitosis within the methodological constraints of the two-dimensional cephalometric analysis and self-reported breathing assessment.

Halitosis is a prevalent condition with considerable psychosocial impact and is among the most common reasons for seeking dental consultation worldwide [2, 17]. Reported prevalence rates vary widely in the literature, which can be attributed to methodological differences, population characteristics, and sociocultural factors [18, 22]. Most cases are intraoral in origin and are primarily associated with bacterial metabolism on the tongue dorsum, gingival inflammation, and reduced salivary flow [19, 23, 24]. In the present study, the prevalence of halitosis was 8.9%, which was lower than that reported in population-based studies. This finding can be explained by the exclusion of individuals with active caries, periodontal disease, or poor oral hygiene, thereby allowing the analysis to focus on non-oral contributing factors, such as airway morphology.

Tooth brushing frequency and oral dryness were significantly associated with halitosis severity, supporting previous evidence that inadequate oral hygiene and salivary dysfunction are major contributors to intraoral malodor [2, 25]. However, no significant association was found between mouth-breathing and halitosis. This finding may be related to the use of self-report questionnaires for breathing pattern assessment. Although mouth breathing has been shown to reduce salivary flow and alter mucosal hydration [5, 6, 26], several studies have suggested that its effect on halitosis may be limited when evaluated under controlled clinical conditions [27, 28]. Moreover, considering that the study population consisted of orthodontic patients who had already undergone preliminary oral health management, the observed associations may be underestimated and could be more pronounced in the general clinical population.

The significant association between oral dryness and halitosis observed in this study is consistent with the established role of salivary flow in maintaining oral homeostasis [2, 23]. Reduced salivary flow facilitates the accumulation of anaerobic bacteria and production of VSCs, which are the primary contributors to oral malodor [23, 24]. In this context, oral dryness may represent a key functional factor influencing halitosis, even in individuals without overt oral pathology [2, 24]. These findings are in line with previous studies reporting that salivary dysfunction and oral hygiene are among the most significant determinants of halitosis [2, 23, 24]. In contrast, the contribution of airway-related factors remains unclear and appears to be context-dependent, varying according to population characteristics and methodological approaches [26–28].

Collectively, these findings suggest that local and functional oral factors may play a more dominant role than anatomical airway characteristics in the development of halitosis, particularly in relatively healthy populations.

Table 4. Multivariate logistic regression analysis of factors associated with self-reported halitosis.

Variable	Category	No *n* (%)	Yes *n* (%)	Univariate OR (95% CI)	*p*-value	Multivariate OR (95% CI)	*p*-value
Physiological halitosis (morning breath)	No	25 (33.8)	2 (5.1)	Reference		Reference	
	Yes	49 (66.2)	37 (94.9)	9.439 (2.101–42.395)	**0.003***	11.565 (2.286–58.513)	**.003***
Oral dryness	No	55 (74.3)	21 (53.8)	Reference		Reference	
	Yes	19 (25.7)	18 (46.2)	2.481 (1.095–5.620)	**0.029***	2.857 (1.015–8.043)	**.047***
Mouth breathing	No	47 (63.5)	25 (64.1)	Reference		Reference	
	Yes	27 (36.5)	14 (35.9)	0.975 (0.435–2.186)	0.951	0.712 (0.251–2.021)	.523
Sagittal classification	Class I	19 (25.7)	20 (51.3)	Reference		Reference	
	Class II	25 (33.8)	11 (28.2)	0.418 (0.162–1.078)	0.071	0.608 (0.148–2.500)	.490
	Class III	30 (40.5)	8 (20.5)	0.253 (0.093–0.689)	**0.007***	0.109 (0.018–0.652)	**.015***
Vertical classification	Normodivergent	35 (47.3)	24 (61.5)	Reference		Reference	
	Hyperdivergent	20 (27.0)	3 (7.7)	0.225 (0.062–0.813)	.023*	0.235 (0.032–1.739)	.156
	Hypodivergent	19 (25.7)	12 (30.8)	1.287 (0.546–3.031)	.564	0.453 (0.072–2.848)	.399
Airway width (categorical)	Wide ($\geqslant$13 mm)	31 (41.9)	16 (41.0)	Reference		Reference	
	Narrow ($<$13 mm)	43 (58.1)	23 (59.0)	1.036 (0.471–2.278)	.929	0.895 (0.170–4.716)	.896
ANB angle	Mean $\pm$ SD	1.22 $\pm$ 4.18	2.06 $\pm$ 4.09	1.051 (0.955–1.156)	0.310	0.908 (0.719–1.147)	.417
SN–GoGn angle	Mean $\pm$ SD	32.10 $\pm$ 7.59	29.85 $\pm$ 5.32	0.953 (0.900–1.010)	0.104	0.868 (0.740–1.019)	.084
Airway width (mm)	Mean $\pm$ SD	12.63 $\pm$ 3.70	12.18 $\pm$ 3.91	0.968 (0.872–1.075)	0.545	0.948 (0.834–1.079)	.419

OR: odds ratio; CI: confidence interval.
Statistically significant values are shown in bold.

Table 5. Agreement and diagnostic performance of self-reported and physiological halitosis compared with clinical assessment.

Variable		Clinical halitosis absent *n* (%)	Clinical halitosis present *n* (%)	Kappa (*p*-value)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Self-reported halitosis	No	73 (70.9)	1 (10.0)	0.264 (<0.001)[a]	90.0	70.9	23.1	98.6	72.6
	Yes	30 (29.1)	9 (90.0)						
Physiological halitosis (morning breath)	No	27 (26.2)	0 (0.0)	0.059 (0.063)	100.0	26.2	11.6	100.0	32.7
	Yes	76 (73.8)	10 (100.0)						

PPV: positive predictive value; NPV: negative predictive value.

Clinical halitosis was determined using organoleptic assessment.

[a] Statistically significant.

Table 6. Diagnostic performance of the portable breath analyzer compared with organoleptic assessment.

Parameter	Value
Kappa coefficient	0.698
Sensitivity (%)	80.0
Specificity (%)	96.1
PPV (%)	66.7
NPV (%)	98.0
Accuracy (%)	94.7

Adequate airway dimensions are essential for normal respiration and are influenced by age, sex, and craniofacial growth patterns [29]. However, previous studies investigating the relationship between airway size and skeletal patterns have yielded inconsistent results. While some authors have reported significant associations between sagittal or vertical skeletal discrepancies and airway dimensions [7, 11], others found no such relationship [30, 31]. In line with these findings, the present study did not demonstrate significant differences in airway dimensions across sagittal or vertical skeletal patterns. These discrepancies in the literature may be attributed to methodological variability, including differences in skeletal assessment parameters, imaging modalities (two-dimensional cephalometry vs. cone beam computed tomography; CBCT), and individual postural or growth-related factors.

Airway obstruction and nasal blockage have been associated with mouth breathing and halitosis in previous studies [32, 33]. Nevertheless, no significant relationship was observed between airway width and halitosis scores in the present study. This finding may be explained by the exclusion of individuals with upper respiratory tract infections and inclusion of a systemically healthy study population. Furthermore, airway evaluation was based on two-dimensional cephalometric measurements, and breathing patterns were assessed using self-reported data, which may have limited the accuracy of airway characterization.

Future studies employing three-dimensional imaging modalities, such as CBCT and objective respiratory assessments (e.g. polysomnography or airflow measurements), are warranted to further elucidate the potential relationship between airway characteristics and halitosis.

Similarly, vertical skeletal patterns were not independently associated with self-reported halitosis after adjustment for potential confounders. Although hyperdivergent individuals tended to demonstrate lower odds in the univariate model, this association did not remain significant in the multivariate analysis, suggesting that vertical craniofacial morphology alone may not play a major role in the perception of halitosis.

Although the Class III skeletal pattern emerged as a statistically significant predictor in the multivariate model, this finding should be interpreted with considerable caution. The number of participants with clinically confirmed halitosis was low, which may have reduced model stability and increased the risk of overfitting. The wide CIs observed in some regression estimates further indicate limited precision. Therefore, the observed association may represent a chance finding rather than a true biological relationship. These findings should be considered hypothesis-generating rather than confirmatory and should be validated in larger studies including a greater number of halitosis-positive individuals. Consequently, this result should be interpreted as exploratory and requires confirmation in adequately powered studies.

First, airway assessment was based on two-dimensional cephalometric measurements, which may not adequately reflect functional airway dynamics. Second, the study population consisted of systemically healthy orthodontic patients without active respiratory conditions, potentially limiting the variability in airway-related parameters. Furthermore, halitosis is primarily driven by intraoral factors and the contribution of airway-related variables may be indirect and secondary, particularly in populations with controlled oral health conditions.

One of the key findings of this study was that self-reported halitosis was strongly associated with physiological halitosis patterns and oral dryness, whereas no significant relationship was observed with craniofacial morphology or airway dimensions. This suggests that the perception of halitosis in orthodontic patients is primarily influenced by functional and subjective factors rather than by anatomical characteristics [1, 3].

Furthermore, the weak agreement between self-reported halitosis and objective measurements indicates a discrepancy between patient perception and clinical findings. Despite its high sensitivity, the low positive predictive value suggests that individuals may overestimate the presence of halitosis [12]. This discrepancy may be partly explained by the tendency of individuals to perceive physiological halitosis, particularly morning breathing, as a pathological condition. The lack of association between physiological halitosis and objective measurements further supports the concept that morning breathing represents a physiological variation rather than a pathological condition [15].

The organoleptic method remains the clinical reference standard for halitosis assessment because it directly reflects the perceived odor intensity [16]. However, its subjective nature and dependence on the examiner results in limited reproducibility [12]. Instrument-based methods, including portable breath analysis devices, provide quantitative measurements of VSCs and allow for improved standardization. Rather than serving as alternatives, organoleptic and device-based assessments should be regarded as complementary diagnostic tools [34].

In the present study, the YRY Smart Breath Odor Detector demonstrated a statistically significant and substantial level of agreement with organoleptic assessment ($\kappa = 0.698$). The device also showed high specificity (96.1%), high negative predictive value (98.0%), and high overall diagnostic accuracy (94.7%). Although these findings do not support its use as a standalone diagnostic tool, the device may provide practical support as an adjunctive screening method in clinical settings when used under standardized conditions.

One of the main strengths of this study is that it is among the few investigations comparing a portable breath analysis device with the organoleptic method for the assessment of halitosis. Furthermore, this study provides a unique contribution to the literature by examining craniofacial and airway parameters in a systemically healthy population in which intraoral etiologic factors were carefully eliminated. Nevertheless, this study has several limitations. Airway evaluation was based on two-dimensional cephalometric radiographs, which restrict detailed anatomical assessment compared to three-dimensional CBCT imaging. Breathing patterns were assessed using self-reported questionnaire data without objective clinical or functional validation, which may have introduced misclassification bias and limited the accuracy of the classification. Additionally, all organoleptic assessments were performed by a single examiner; therefore, inter-observer agreement could not be evaluated, which may represent a potential source of observer-related bias. The exclusion of individuals with active caries, periodontal disease, or poor oral hygiene resulted in a relatively selected study population. While this approach allowed for the isolation of non-oral contributing factors, it may limit the generalizability of the findings and attenuate the observed associations. Furthermore, tongue coating, plaque accumulation, periodontal indices, salivary flow rate, and quantitative VSC measurements were not evaluated. Therefore, interpretations regarding oral hygiene and salivary factors should be considered indirect and interpreted with caution.

Finally, although the overall sample size met the *a priori* calculation, the number of halitosis-positive participants was relatively low. In addition, the sample size calculation was based on one-way ANOVA rather than logistic regression modeling. Therefore, the multivariable regression analyses should be regarded as exploratory and interpreted with caution, as limited event numbers may reduce model stability, increase the risk of overfitting, and result in imprecise effect estimates.

5. Conclusion

This study demonstrated that the prevalence of halitosis among systemically healthy young individuals scheduled for orthodontic treatment is relatively low (8.9%). Within the limitations of this study, halitosis appeared to be more closely associated with self-reported oral dryness and tooth-brushing frequency than with airway morphology or craniofacial skeletal patterns. In particular, tooth brushing frequency and self-reported oral dryness emerged as significant determinants of halitosis, underscoring the importance of local oral factors, even in clinically healthy populations.

In addition, self-reported halitosis was influenced by physiological breath patterns and oral dryness, highlighting the role of functional and subjective factors in the perception of halitosis.

A statistically significant and substantial level of agreement was observed between the portable breath analyzer and the organoleptic method. Although this finding does not support the use of handheld devices as standalone diagnostic tools, such devices may still serve as practical adjuncts for halitosis screening in clinical settings when used under standardized conditions.

Future large-scale prospective studies incorporating three-dimensional airway imaging and objective respiratory assessments are warranted to further clarify the role of airway-related factors and refine the diagnostic strategies for halitosis.

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Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

Conflict of interest

The authors declare no conflicts of interest.

Clinical relevance and future direction

The findings of this study highlight the importance of integrating subjective and objective approaches in the assessment of halitosis in routine dental practice. When used in conjunction with clinical evaluation and patient self-reports, portable breath analyzers may provide supportive information and improve patient awareness, particularly in orthodontic and preventive dental care settings. In addition, the influence of physiological breath patterns and oral dryness on self-perceived halitosis underscores the need to consider functional and perceptual factors during clinical assessments.

Future research should incorporate three-dimensional airway analyses using cone-beam computed tomography (CBCT) along with biochemical evaluation of volatile sulfur compounds (VSCs). Moreover, expanding the study population to include individuals with systemic and respiratory conditions may help further elucidate the complex interactions between the oral environment, airway morphology, and the mechanisms underlying breath odor generation.

Ethical statement

This study was approved by the Non-Interventional Clinical Research Ethics Committee of Uşak University Faculty of Medicine (Approval No: 216–216–18, Date: 12 October 2023).

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