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Original Article

Anterior open bite and its relationship with dental arch dimensions and tongue position during swallowing and phonation in individuals aged 8–16 years: A retrospective case–control study

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Keywords
Open bite
Lingual function

Summary

Objective > To determine the relationship between AOB and factors such as dental arch dimensions and tongue position during swallowing and phonation.
Material and Methods > A case–control study was performed in two groups: 132 children with Anterior Open Bite (AOB) and 132 with normal vertical overbite (NVO), aged 8-16 years selected from the records taken by a previous study from five public schools. Dental arch dimensions were assessed through digitalized study models. Swallowing was evaluated using the Payne technique, and phoniatric assessment included an adaptation of the articulation test used to describe phonemes. Statistical analysis: Chi-Square or Fisher's exact test for comparisons between qualitative variables and the Mann Whitney or T-student were applied to compare the dental arch dimensions according to bite type. A logistic regression model was applied to control the effect of confusion between independent variables and to describe its simultaneous effect on the type of bite.
Results > Intercanine, interpremolar and intermolar widths showed higher values in AOB patients with a mean deviation (MD) of 0.536 ($P = 0.031$), 0.60 ($P = 0.043$) and 1.15, ($P < 0.001$) respectively. Distortions caused by tongue interposition and thrust, tongue protrusion during swallowing, mandibular arch intermolar width, total maxillary arch length, maxillary arch perimeter, and posterior arch depth accounted for 64.6% of AOB and allowed for correct predictions in 83.8% of the cases observed in the study population.

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Conclusions > A significant association between tongue position and function, as well as alterations such as tongue interposition and thrust during swallowing and phonation in individuals with AOB, were observed. There is a relationship between AOB and the presence of a wider mandibular arch and a narrower, longer, and deeper maxillary arch.

Introduction

Anterior open bite (AOB) is defined as the loss of contact between anterior maxillary and mandibular teeth; it may occur regardless of patients' skeletal patterns, and [1] it is one of the most complex alterations treated by orthodontists. This type of malocclusion might negatively impact patients' quality of life because it affects their facial aesthetics and decreases their communication ability [1,2]. Although its aetiology is considered multifactorial, it has been associated with interactions among different factors, such as heritage, environment, lifestyle habits, altered function, posture alterations, neuromuscular deficiencies, and airway obstruction [1,3].

Regarding the epidemiology of this malocclusion, its prevalence has been reported in different populations and ranges from 2.7% in children aged 8–16 years in Colombia and 12.1% in children aged 5 years in Brazil up to 16% in African-Americans and 4% in Caucasians in the United States [4–6].

Alterations in tongue position during different functions are recognized as one of the environmental factors that promote AOB development. Literature has reported that tongue function, posture, and size affect dental position, dental arch, and maxillary teeth development [1]. Lifestyle habits, such as finger sucking, may prevent correct incisor eruption and lead to an adaptive low tongue position, along with an increase in cheek pressure, may result in deepening of the palate, narrowing of the arch, and posterior cross bite combined with AOB [7–9]. Conversely, AOB is considered a malocclusion that is most commonly associated with phonation because 80% of speech movements are performed in the anterior region of the mouth [5].

Despite the wide array of information available in the scientific literature, there is no agreement regarding AOB aetiology [5,7–9], given that some patients may present several associated factors without evidencing this malocclusion, whereas other patients may present this alteration without any associated factor. Moreover, some researchers have suggested that tongue-tip protrusion during swallowing is associated with AOB; however, other researchers have suggested that this protrusion is the result of the functional adaptation of an existing malocclusion [10]. Most of the studies that were found are reviews or observational studies that cannot support association or aetiology of their findings [3,5], only a few were analytical [4], but still do not offer sufficient knowledge as they were performed using existing epidemiological data. Also, the factors evaluated in the literature are analysed individually, which shows a difficulty to relate them properly. Therefore, there is no clear evidence on the relationship between AOB, dental arch dimensions, and tongue position during phonation and swallowing.

The present study aimed to establish the relationship between AOB and factors such as tongue position during swallowing, phoniatric alterations, and dental arch dimensions in children and adolescents aged 8–16 years.

Glossary

AOB	anterior open bite
NVO	normal vertical overbite

Materials and Methods

A case–control study was conducted in a sample selected from the records of the Orthodontic Department described in a previous study [11] that consisted in 264 cast models belonging to children from five public schools obtained from a sample of 14 clusters and allocation proportional according to the number of schoolchildren per institution. The sample included 132 children with AOB (AOB group) and 132 children with normal vertical overbite (NVO; NVO group). To calculate the sample size, the total school population between 8-16 years was considered, which raised to 22,955 schoolchildren, with an AOB prevalence of 2%, a confidence level of 95%, and a margin error of 7% [5], having an equal distribution of students from the five schools selected, which have primary, intermediate and secondary levels in their facilities.

A 1:1 matching was performed, and after identifying each AOB case, children with NVO were chosen (who were classmates of children with AOB and were of the same age and gender). This study was approved by the Bioethics Committee from Universidad Cooperativa de Colombia under record No. 0800-0020 and parents and children signed an informed consent.

Inclusion criteria included children and adolescents aged 8-16 years who presented with AOB or NVO with complete incisor eruption, children with presence of class I molar or class I canine relationship. Exclusion criteria comprised children with a mental syndrome, with facial and/or skeletal malformations, who had undergone interceptive and/or corrective treatment, with posterior crossbite, and with finger-sucking habits and lower lip sucking habits.

The presence of AOB was determined if the anterior teeth did not reach the occlusion line or touch the antagonists by at least 1 mm, a measure that was taken from the incisal edge of the maxillary teeth to the incisal edge of the mandibular teeth. NVO was determined if the incisal edges were in contact with the palatal surface of the maxillary incisors, and if one third of the mandibular incisor crown was covered. AOB severity was classified according to the degree of separation observed between incisors as mild (up to 1 mm), moderate (1–5 mm), and severe (> 5 mm) [12].

Cast dental arch dimensions measured were as follows: upper/lower intermolar width, upper/lower intercanine distance, upper/lower length, upper/lower intercanine distance, upper/lower perimeter, upper/lower total length, upper/lower interpremolar width, upper anterior length, upper anterior depth and upper posterior depth (*table I*). The upper and lower casts obtained for both AOB and NVO were digitalized by the i3D company using an optical 3D scanner (The ATOS Core Kinematics, Canada) and a lens at a distance of 440 mm, a measuring volume of 300 × 230 × 230 mm, and an accuracy scanner of 15 µm. Once the models were digitalized, measurements were taken using the GOM inspection software. Rugae patterns and maxillary measures [13] were assessed by a single examiner after calibration.

An evaluation standardization of data collection instruments was performed. A pilot test was also conducted for intra- and interobserver calibration of clinical analysis and the application of the Payne technique in five patients from pregraduate and postgraduate students at Universidad Cooperativa de Colombia (kappa index = 0.95 for interobservers and 0.99 for intraobservers).

An intra and inter-observer evaluation was carried out with an expert to standardize arch measurements, from 10 virtual 3D models in which all measurements were made by two independent observers (interobserver) and at two different times (intraobserver). The estimation of the errors was carried out through the Dahlberg formula:

$$TEM = \sqrt[2]{\frac{\sum(d_1 - d_2)^2}{2n}}$$

where *d* represents the difference between two measurements and *n* is the number of pairs. Method errors should not be higher than 0.6 mm (0.05–0.6 mm).

Swallowing was assessed using the Payne technique, which was carried out in a dark room. First, children were asked to stick their tongues out and then the excess of saliva was cleaned with a gauze. Fluorescein was applied first on the right edge and then consistently over the frontal area without pausing until the left edge was reached. Patients were immediately asked to keep their tongues out and swallow only once and then open their mouth. They were asked to not talk during the procedure. An approximation was performed using a Payne lamp to observe the contact points of the tongue during the oral phase of the

Table I

Dental arch measurements.

Upper/Lower intermolar width	Straight line measured between the centre point of the mesial fossa of the right molar and the mesial fossa of the left molar. The measurement was not performed when one or both of the molars were absent
Upper/Lower Intercanine distance	Straight line between cusp tips of right and left canines or the middle of the facet resulting from attrition. The measurement was not performed when one or both of the canines were absent
Upper/Lower Length	Straight distance from interdental papilla tip between central incisors to a tangent through mesial surfaces of the second molars
Upper/lower intercanine distance	Straight line between cusp tips of right and left canines or the middle of the facet resulting from attrition. The measurement was not performed when one or both of the canines were absent
Upper/lower perimeter	Sum of four segments: from distal surface of primary second molars or mesial surface of first permanent molar on one side (passing over the contact points) to mesial deciduous or permanent canine on both sides. The other segments were measured from mesial deciduous or permanent canine to a point between two central points on both sides
Upper/lower total length	Straight distance from interdental papilla tip between central incisors to a tangent through mesial surfaces of the second molars
Upper/Lower Interpremolar width	Straight line measured between buccal cusp of the right first premolar and the buccal cusp of the left first premolar. The measurement was not performed when one or both of the molars were absent
Upper anterior length	Distance form interpremolar or deciduous intermolar papilla to the contralateral side
Upper posterior length	Distance form intermolar papilla to the contralateral side

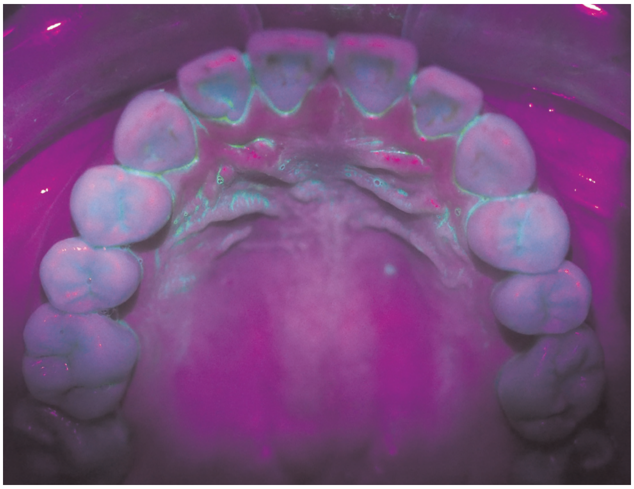

FIGURE 1

Application of the Payne technique in the upper arch. Green markings on the teeth and palatal mucosa where the tongue touches during swallowing

swallow (*figure 1*). The selected variables that were marked in the study included the tongue touching the gingival margin during swallowing, making contact with at least half of the palatal side of the maxillary and mandibular teeth, completely protruding between adjacent teeth, touching the palatal rugae, or touching the mandibular teeth [14].

The articulation test performed during the phoniatric evaluation, was modified to achieve a personal evaluation of the Spanish spoken in Colombia, thus avoiding misinterpretations or incorrect data analysis. This assessment was based on the scores provided by Tobias Corredera Sánchez, who described phonemes, and by Bernal and Baquero, who described consonant sounds. Articulation points and types were evaluated in the following manner—place of articulation: bilabial/m/p/b/; labiodental:/f/v/; interdental:/none/; dental:/t/d/; alveolar:/s/n/l/r/rr/; palatal:/y/ll/ch/ñ/; velar:/k/g/j/x/and manner of articulation: occlusive:/p/b/t/d/k/; fricative:/f/v/s/y/ll/g/j/m/n/ñ/; lateral:/l/; vibrant:/r/rr/. According to the manner in which each student pronounced these phonemes, speech evaluation was classified as normal, distorted by tongue interposition, or distorted by tongue thrust, substitution, or omission. This methodology was used in a previous study [5]. The sample was divided into two groups according to age to identify whether it had any influence on the variables. The first group comprised pupils from 8 to 12 years of age and the second, pupils between 13 and 16 years of age.

Statistical analysis: A univariate analysis was carried out through the estimation of proportions for the qualitative variables (gender, swallowing and phonation disorders) and summary measures (central tendency, position and dispersion) for the quantitative variables (age and dimensions of the dental arch). Bivariate analysis was performed to explore the association between swallowing disorders and phonation with bite type, through Pearson's chi-square test or Fisher's exact test. The comparison of the dental arch dimensions between the two study groups was carried out through Student's t tests or Mann-Whitney U tests, after verification of compliance with the assumption of normal distribution using the Smirnov Kolmogorov statistic with Lilliefors correction. A binomial logistic regression model was performed after verification of its goodness of fit through the Hosmer Lemeshow test to control the confounding effect between the independent variables and to identify their simultaneous effect of the possibilities of presenting AOB. The exponentials of the β coefficients were interpreted in terms of the indicators of epidemiological association odds ratio "OR".

All analyses were performed on the overall collected data, and a *P*-value of < 0.05 was considered statistically significant. Analyses were performed with IBM® SPSS statistical software package, 23.0 version.

Results

A total of 132 children with AOB were analysed, 59.1% were girls with an average age of 12 ± 3 years and 51.5% of the 132 NVO were girls with an average age of 11 ± 2 years (*table II*).

TABLE II

Demographic characteristics of the study population.

	Type of Bite			
	Anterior Open Bite		Normal Vertical Overbite	
Sex	**Frequency**	**%**	**Frequency**	**%**
Female	78	59.1%	68	51.5%
Male	54	40.9%	64	48.5%
Age, years	**Mean ± SD**	**IQR**	**Mean ± SD**	**IQR**
Female	12 ± 3	12 (9–14)	11 ± 2	11 (10–14)
Male	12 ± 3	13 (10–14)	11 ± 2	11 (9–13)

When evaluating and comparing mandibular arch dimensions within the two groups, the average arch width showed higher values with significant differences in the intercanine width [mean deviation (MD) = 0.536, *P* = 0.031], interpremolar width (MD = 0.60, *P* = 0.043), and intermolar width (MD = 1.15, *P* < 0.001) in the AOB group. Comparisons between the average mandibular arch perimeter and average mandibular arch length did not reveal any significant differences between the two groups.

Regarding maxillary arch measurements, higher average values with significant differences were found in the AOB group for the following variables: total upper length (MD = 0.99; *P* = 0.001), upper anterior depth (MD = 1.56; *P* < 0.001), and upper posterior depth (MD = 1.85; *P* < 0.001). Comparisons performed on

TABLE III

Dental arch dimensions observed in the AOB and NVO.

Age Group	Variable	Type of Bite				*P*
		Normal Vertical Overbite		Anterior Open Bite		
		Mean ± ED	Median (IC)	Mean ± ED	Median (IC)	
8–12 years	Lower intermolar width	40.56 ± 2.42	40.63 (36.31–42.32)	42.09 ± 2.66	42.29 (37.83–43.98)	< 0.001[1]
	Lower Interpremolar width	31.26 ± 2.16	31.27 (27.73–32.64)	32.18 ± 2.44	32.19 (28.80–33.52)	0.018[1]
	Lower Intercanine distance	26.56 ± 1.92	26.78 (23.38–27.75)	27.02 ± 2.14	26.86 (23.55–28.23)	0.157[1]
	Lower perimeter	70.71 ± 3.79	70.91 (65.68–73.09)	72.04 ± 3.93	72.20 (66.10–74.66)	0.031[1]
	Lower Length	22.10 ± 1.98	21.97 (19.29–23.55)	22.69 ± 6.73	22.06 (18.08–23.57)	0.816[2]
	Upper intermolar width	46.73 ± 3.07	46.99 (42.01–48.79)	46.90 ± 3.26	47.30 (41.06–48.93)	0.727[1]
	Upper intercanine distance	33.70 ± 2.72	33.49 (31.66–35.32)	32.95 ± 2.93	32.50 (31.61–34.64)	0.122[2]
	Upper anterior width	35.23 ± 2.66	35.28 (30.18–37.11)	34.82 ± 2.88	34.68 (30.55–36.51)	0.348[1]
	Upper perimeter	74.17 ± 4.46	74.40 (67.14–77.11)	73.41 ± 5.16	73.95 (65.06–76.75)	0.308[1]
	Upper anterior length	18.97 ± 2.53	18.69 (15.64–20.40)	18.81 ± 2.15	18.68 (15.52–19.84)	0.854[2]
	Upper total length	26.34 ± 1.96	26.43 (23.27–28.03)	27.02 ± 2.39	27.00 (23.46–28.49)	0.046[1]
	Upper anterior depth	14.17 ± 2.23	14.16 (10.76–15.46)	15.04 ± 2.05	15.25 (10.86–16.43)	0.010[1]
	Upper posterior depth	16.25 ± 2.25	16.19 (12.94–18.13)	17.08 ± 2.34	17.10 (13.64–18.66)	0.023[1]
13–16 years	Lower intermolar width	40.54 ± 2.50	41.04 (38.83–42.18)	41.22 ± 2.33	41.15 (39.78–42.25)	0.197[1]
	Lower Interpremolar width	32.11 ± 2.13	31.74 (30.67–33.81)	32.05 ± 2.37	32. 2145 (30.28–33.30	0.900[1]
	Lower Intercanine distance	26.92 ± 1.92	26.77 (25.25–28.41)	27.40 ± 1.85	27.56 (26.66–28.55	0.123[2]
	Lower perimeter	69.96 ± 4.34	70.09 (67.30–72.09)	69.96 ± 3.86	70.22 (67.15–72.83	0.703[2]
	Lower Length	21.06 ± 2.12	20.87 (20.00–22.88)	20.76 ± 1.93	20.94 (19.34–22.22)	0.493[1]
	Upper intermolar width	47.40 ± 2.64	47.02 (45.27–50.18)	47.81 ± 3.06	47.43 (46.09–49.44)	0.515[1]
	Upper intercanine distance	34.56 ± 2.29	34.99 (32.77–36.00)	34.96 ± 2.38	35.10 (33.38–36.40	0.421[1]
	Upper anterior width	36.17 ± 2.82	35.89 (33.75–37.66)	36.47 ± 3.46	36.63 (34.68–38.17	0.661[1]
	Upper perimeter	73.99 ± 5.29	73.62 (69.00–77.66)	73.13 ± 5.83	72.98 (69.05–75.17	0.345[2]
	Upper anterior length	18.23 ± 2.16	18.41 (16.49–19.52)	19.28 ± 2.15	19.08 (18.24–20.27)	0.0231
	Upper total length	25.12 ± 1.99	25.48 (23.83–26.20)	27.02 ± 3.01	26.59 (24.94–28.57)	< 0.001[1]
	Upper anterior depth	15.36 ± 2.14	15.07 (13.77–16.74)	17.26 ± 2.27	17.20 (16.51–18.85)	< 0.001[2]
	Upper posterior depth	18.08 ± 2.20	18.34 (16.87–19.57)	20.40 ± 2.08	20.55 (18.85–21.60)	< 0.001[1]

[1] Student's *t*-test.

[2] Mann–Whitney's U-test.

TABLE IV

Frequency of phonation and swallowing alterations observed in the AOB and NVO groups.

			Type of Bite Anterior Open Bite		Normal Vertical Overbite		
			Count	%	Count	%	*P*
8–12 years	Phonation						
	Distortion						
	Tongue Interposition	No	33	34.0	64	66.0	< 0.001 [1,**]
		Yes	64	88.9	8	11.1%	
	Tongue Thrust	No	71	73.2	72	100.0	< 0.001 [2,**]
		Yes	26	100.0	0	0.0%	
	Substitution	No	1	100.0	0	0.0%	1,000 [2]
		Yes	96	57.1	72	42.9	
	Swallowing						
	Gingival Margin	No	70	56.0	55	44.0	0.536 [1]
		Yes	27	61.4	17	38.6	
	Palatal Surface	No	72	54.1	61	45.9	0.099 [1]
		Yes	25	69.4	11	30.6	
	Protruding Tongue	No	83	54.2	70	45.8	0.010 [2,*]
		Yes	14	87.5	2	12.5	
	Palatal Rgae	No	70	70.0	30	30.0	< 0.001 [1]
		Yes	27	39.1	42	60.9	
	Lower Teeth	No	93	56.7	71	43.3	0.395 [2]
		Yes	4	80.0	1	20.0	
13–16 years	Phonation						
	Distortion						
	Tongue Interposition	No	12	21.8	43	78.2	< 0.001 [1,**]
		Yes	23	57.5	17	42.5	
	Tongue Thrust	No	25	29.8	59	70.2	< 0.001 [2,**]
		Yes	10	90.9	1	9.1	
	Substitution	No	35	100.0	60	100.0	NA
		Yes	0	0	0	0	
	Swallowing						
	Ginvival Margin	No	26	40.0	39	60.0	0.348 [1]
		Yes	9	30.0	21	70.0	
	Palatal Surface	No	26	34.2	50	65.8	0.288 [1]
		Yes	9	47.4	10	52.6	
	Protruding Tongue	No	27	31.8	58	68.2	0.005 [2,**]
		Yes	8	80.0	2	20.0	
	Palatal Rugae	No	30	46.9	34	53.1	0.004 [1,**]
		Yes	5	16.1	26	83.9	
	Lower Teeth	No	31	34.4	59	65.6	0.060 [2]
	Yes	4	80.0	1	20.0		

[*] *P* = 0.05; [**] *P* = < 0.01.
[1] Chi^2 test.
[2] Fisher's exact test.

the other maxillary arch variables did not show any significant differences.

When evaluating the results of the comparison between age groups, no statistically significant differences were found. The mandibular arch dimension in children between 8–12 years showed higher values with statistical differences for interpremolar width (MD = 0.92; $P = 0.018$), intermolar width (MD = 1.53; $P < 0.001$) and arch perimeter (MD = 1.49; $P = 0.031$) in the AOB group.

For the group of 13 to 16 years, there were no differences in arch dimensions between AOB and NVO (*table III*).

For the maxillary arch, both groups presented higher values with statistical differences in children with AOB in the variables of total upper length (8–12 years: MD = 0.68; $P = 0.046$; 13–16 years: MD = 1.47; $P < 0.001$) and total upper depth (8–12 years: MD = 0.8; $P = 0.023$; 13–16 years: MD = 2.32; $P < 0.001$). In the anterior upper depth, children from 8–12 years and AOB showed higher values (MD = 1.08; $P < 0.010$), similar to children between 13–16 years ($P < 0.001$).

For anterior upper length children with AOB and 8–12 years presented higher values (MD = 0.85; $P = 0.023$) (*table III*).

With respect to the evaluation of the tongue position during swallowing and its estimated frequencies, a higher proportion of cases with protruded tongue and tongue in contact with the palatal surface of incisors was observed in the AOB group than in the NVO group ($P = 0.001$ and 0.049, respectively), whereas tongue contact with palatal rugae during swallowing was most frequently observed in the NVO group ($P < 0.001$).

Regarding phonation distortion, a higher proportion of individuals with distortions caused by tongue interposition were found in the AOB group (77.7%; $P < 0.001$) than in the NVO group. Similarly, the AOB group showed the highest proportion of individuals with distortions caused by tongue thrust (97.3%; $P < 0.001$), whereas only one case of distortion caused by substitution was observed in the NVO group. Regarding the different types of articulation evaluated in phonation tests, the most frequent articulation was dental articulation (approximately 90% of cases) and the least frequent was palatal articulation (approximately 13% of cases).

With respect to the tongue position during swallowing, both group ages showed higher values in AOB children (8–12 years: $P < 0.001$; 13–16 years: $P < 0.001$), whereas the palatine rugae tongue contact was more frequently present in the NVO group for both age groups (8–12 years: $P < 0.001$; 13–16 years: $P = 0.004$) (*table IV*). Phonation distortion in both age groups presented higher values for lingual interposition in individuals with AOB (8–12 years: $P < 0.001$; 13–16 years: $P < 0.001$), while tongue thrust was higher only for the group of 8–12 years $P < 0.001$; 13–16 years: $P < 0.001$) (*table IV*). With respect to articulation types, dental articulation was more frequent (89.5% in children between 8–12 years and 82.6% in the group of 13–16 years). Palatal articulation was the least common with only 19% in both groups.

An applied logistic regression model was performed adjusting the independent variables that are truly related to AOB development and excluding variables whose association with AOB may be caused by the confusion phenomenon. The simultaneous effects of associated variables were estimated, and distortions caused by tongue interposition and thrust, tongue protrusion during swallowing, lower intermolar width, total upper length, upper perimeter, and posterior depth accounted for 64.6% of AOB, which accurately predicted 83.8% of the cases in the studied population (*table V*). The effect of collinearity between variables was explored with correlation tests between the quantitative variables, which did not show statistical significance.

As an additional result obtained from the model, it was found that the possibility of developing AOB was 12 to 50 times higher

TABLE V

Logistic regression model for OR adjustment.

	OR	95% CI	*P*	Nagelkerke R-squared
Tongue interposition	0.083	0.038–0.181	0.000**	0.646
Tongue thrust	0.020	0.002–0.166	0.000**	
Protruding tongue	0.233	0.059–0.915	0.037*	
Lower intermolar width	0.841	0.713–0.993	0.041*	
Upper total length	0.581	0.452–0.746	0.000**	
Upper posterior depth	0.732	0.631–0.849	0.000**	
Upper perimeter	1.197	1.072–1.335	0.001**	

$^{*}P = 0.05$.
$^{**}P = < 0.01$.

Table VI
Logistic regression model for OR adjustment according with age group.

		OR	95% CI	*P*	Nagelkerke R-squared
8–12 years	Lower intermolar width	1.515	1.207–1.902	< 0.001	
	Upper intercanine distance	0.602	0.469–0.771	< 0.001	
	Upper total length	1.590	1.197–2.113	0.001	0.626
	Lingual interposition	27.818	7.679–100.765	< 0.001	
	Palatal Rugae	0.248	0.092–0.667	0.006	
	Upper total length	1.408	1.091–1.818	0.009	0.548
13–16 years	Upper posterior depth	1.811	1.337–2.454	< 0.001	
	Lingual interposition	3.915	0.065–0.896	0.034	
	Palatal rugae	0.241	1.228–12.485	0.021	

in individuals with phonation difficulties caused probably by tongue interposition and thrust, than in individuals who did not show these alterations. Similarly, the possibility of patients with AOB to present swallowing difficulties was 3.3 times higher than other patients, which could be related to the presence of tongue protrusion.

To compare the logistic regression results between age groups, two regression logistic models were performed with adjustment of independent variables associated with AOB and excluding variables with confounding effect. An estimated effect was determined showing that distortion with lingual interposition, lower intermolar width, upper intercanine distance, upper total length and no contact with palatal rugae, explained 62.6% of the cases with AOB and can predict the presence of AOB in children between 8–12 years in 85.7% of cases. For the age group between 13–16 years, lingual interposition, upper total length, posterior upper depth and no contact in palatal rugae can be explained in 54.8% of the presence of AOB and had the ability to predict AOB cases in 83% (*table VI*).

Additional results showed that both age groups with AOB had 27 (8–12 years) and 4 (13–16 years) times more probability to present phonation problems and lingual interposition comparing with the NVO children. Children with AOB in both age groups had 10.8 (8–12 years) and 15.4 (13–16 years) times more possibility to present deglutition problems and no tongue contact to palatal rugae (*table VI*).

Discussion

A case–control study was performed to determine the association between different variables and the presence of AOB. Factors such as tongue position during swallowing, phoniatric alterations, and dental arch dimensions in children with AOB or NVO were evaluated. Distortions caused by tongue thrust (tongue contact with lingual surface of upper incisors), tongue protrusion during swallowing (tongue protruding between upper and lower teeth), lower intermolar distance, total upper length, upper perimeter, and posterior depth were found to account for 64.6% of AOB cases and was correctly predicted in 83.8% of cases in the study population. These results suggest that resting tongue position and tongue position during function define the determination of altered occlusal patterns such as those observed in AOB. Similar findings have also been reported by Fujiki et al. [15] who evaluated the relationship between maxillofacial morphology and tongue movement during swallowing in patients with and without AOB and concluded that tongue function in patients with AOB is closely related to the morphological characteristics of these patients. Similarly, Rogers [16] compared a group of orthodontic patients with a group of school children and found an incidence of abnormal swallowing of 98% in patients with AOB. The present study found that the possibility of developing AOB was 3.3 times higher in patients presenting swallowing alterations caused by tongue protrusion than in patients who do not present these alterations. These results are supported by the findings of a study conducted by Pedrazzi et al. [17] who found that the tongue is the main cause of AOB development and perpetuation, and a study performed by Maspero et al. [18] who described abnormal swallowing as a risk factor for occlusal alterations such as AOB, posterior cross bite, and incisor proclination.

When evaluating the differences between dental arches of children with AOB or NVO, it was found that patients with AOB generally have a narrower anterior portion of the maxillary arch, with lower intercanine distance and higher length and depth. These results are consistent with those reported by Hsu [19] who state that patients with AOB generally have a narrower maxillary arch. In fact, they also suggest that such narrowness is due to the bone base. Moreover, a study performed by Ballanti et al. in 2009 [20] suggested that transversal differences observed in the dental arches of patients with or without AOB show a narrower maxillary arch in patients with AOB both in its skeletal and dentoalveolar areas. Álvarez et al. [12] assessed dental arch characteristics in a population comprising school children with AOB or NVO and found that the arch length was higher in the AOB group than in the NVO group. Similarly, they observed that the AOB group had higher values for posterior and anterior palatal depth than the NVO group. These results support the theory that a low resting tongue position at an early age does not stimulate the maxilla, which in turn hinders transversal development.

In the present study, an increase in the maxillary arch length was observed in patients with AOB, which could be explained by the vestibular inclination of the maxillary incisors reported by Machado et al. in 2014 [4]. Although this characteristic was not directly evaluated in this study, it can be suggested that alterations in tongue position during swallowing and speech, and not just in resting position, may lead to development of dental malposition.

According to the results of the present study, patients with AOB showed a wider mandibular arch. A significant increase was found in the intermolar distance of patients with AOB, which suggests that a low tongue position in these patients leads to a higher transversal development of the lower arch than that of the upper arch. Peat [21] concluded that patients with AOB show a narrow maxillary arch and a wide mandibular arch. Furthermore, Ballanti et al. [20] found that the jaw of patients with AOB shows skeletal narrowness at the gonial and condylar levels, but the dentoalveolar region shows a width that is possibly associated with a low tongue position in these patients.

The analysis of tongue function performed in the present study found that patients with AOB show a protruded tongue position with tongue thrust during swallowing and tongue interposition during speech; furthermore, it was found that their tongue appears to be mostly placed on the palatal surface of the upper incisors instead of on palatal rugae during swallowing, which is what would be expected during normal swallowing according to other studies [18,22]. Alterations in tongue position may stimulate maxillary incisor proclination and enhance AOB development only in cases where the extraoral force posed by the lips is lower than that posed by the tongue. Different authors have assessed the pressure applied on vestibular and intraoral spaces during swallowing and have reported that these pressures are generally unbalanced in patients with AOB [9]. Kawamura et al. [10] used cineradiography to assess tongue movement during swallowing and tongue thrust in patients with AOB and found that the tip and the dorsum of their tongues were placed anteriorly and inferiorly when in the resting posture, which leads to accumulation of negative intraoral pressure. Similarly, the dorsum of the tongue also tends to move and assume an anterior position in these patients, whereas the tip of the tongue protrudes and presses the anterior maxillary and mandibular teeth. However, lip and tongue pressures were not measured in the present study.

Conversely, a study conducted by Dixit et al. [22] demonstrated that most patients with tongue thrust also developed AOB, whereas those without tongue thrust did not show this malocclusion. In addition, patients with AOB showed alterations associated with tongue interposition during speech, such as lisping, which supports the findings reported in the present study, wherein the possibilities of presenting AOB were 12 to 50 times higher in patients with phonation difficulties caused by tongue interposition and thrust than in patients who did not present with these alterations. In particular, patients with AOB and imperfect pronunciation of some consonants, such as s, z, f, and v, excessively thrust their tongues forward while articulating these sounds, which may result in maxillary incisor proclination, as reported by Suzuki et al. [23]. However, it should be noted that this study was performed in a Japanese population with cleft lip and palate. In fact, according to Farronato et al. [24], patients with AOB can perfectly articulate sibilant consonants by adjusting their lower lip to direct the necessary airflow toward the sharp edges of the teeth. In addition, they concluded that the effects of dyslalia on speech organs are not constant, whereas the effects of malocclusion on dyslalia appear to be more relevant and frequent because the latter increases proportionally according to the severity of the malocclusion.

The determination of factors associated with occlusal alterations such as AOB, which contain several elements that may affect its development, as well as variables that cannot be matched in all the patients, represents a challenge for future studies. Therefore, it is difficult to control components such as genetics, parafunctional habits, or even eating habits during a study planning. Although the present study did not include some of the aforementioned variables, a strict control of the inclusion criteria was made to ensure that the evaluated patients did not present oral habits other than alterations in tongue function, thus ensuring control over the main confusion variables.

Regarding the results found when comparing the age groups, the presence of tongue functional alterations during swallowing and speech were similar in both groups, nonetheless younger patients with AOB present more oral habits according to previous studies [25,26]. In individuals where AOB is present after pubertal growth, it is more difficult for the malocclusion to be self-corrected [25]. The younger group presented higher values for arch dimensions, similar to studies where arch dimensions decrease with age [26].

The present study determined the associations between different factors and the presence of AOB, thus contributing to the building of a pathway toward the establishment of the roles played by these factors in AOB aetiology. It is necessary to apply a longitudinal prospective design to gain further control over variables, such as time at which this occlusal alteration appears and perform clinical measurements that are similar to those previously reported.

In conclusion, the findings of the present study indicate an association between AOB and the presence of a wider mandibular arch and a narrow, long, and deep maxillary arch. Tongue position and function was found to be significantly associated with alterations such as tongue interposition and thrust during swallowing and phonation in patients with AOB.

Ethics approval and consent to participate: this study was approved by the Bioethics Committee of Universidad Cooperativa de Colombia under record No. 0800-0020, and parents and children signed an informed consent.

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