



# Correlation between oral muscle pressure and malocclusion in mixed dentition: a cross-sectional study

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Received: 14 March 2024 / Accepted: 27 June 2024 / Published online: 4 July 2024  
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## Abstract

**Objective** To investigate the relationship between oral muscle pressure and malocclusion in the mixed dentition.

**Materials and methods** Maximum tongue, lip and cheek pressure was measured using the Iowa Oral Performance Instrument (IOPI) in 3 patient cohorts: patients with (1) posterior crossbite, (2) class II relationship and (3) a control group of patients without malocclusion. Linear models were used to compare the mean differences in muscle pressure between groups, with correction for age and gender. The imbalance between lips and tongue and between lips and cheeks was calculated by the Delta z-scores of each group.

**Results** A total of 146 participants were included, 46 (mean age  $8.71 \pm 0.85$ ), 41 (mean age  $11.74 \pm 1.17$ ) and 35 (mean age  $10.71 \pm 1.92$ ) in groups 1, 2 and 3 respectively. Patients with malocclusion showed significantly higher lip and lower cheek pressure and imbalance favouring the lips over the tongue compared to controls. Class II,1 patients showed significantly higher tongue pressure than Class II,2. No differences were found in muscle pressure or imbalance between crossbite and Class II nor between crossbite types.

**Conclusion and Clinical Relevance** These findings suggest that oral muscle pressure may be associated with malocclusion. This highlights the importance of functional diagnosis and its implications on the prevention and treatment of malocclusion, as well as on orthodontic stability.

**Keywords** Orthodontics · Oral muscle pressure · Mixed dentition · Oral muscle imbalance · Functional diagnosis

## Introduction

Malocclusion is characterized by the misalignment of teeth and/or an incorrect relationship between the jaws. It is a very prevalent condition that can lead to various dental, functional, esthetic and psychosocial problems. A study conducted by the British NHS in 2006 concluded that one-third of all children could benefit from orthodontic treatment [1].

The etiology of malocclusion is considered to be multifactorial, with both genetic and environmental influences playing a role [2]. Among others, oral muscle dysfunction has been suggested to be an etiological factor of malocclusion [3–5]. According to the functional matrix theory [6], developed by Melvin Moss, the forces generated by the (peri)oral muscles act as a functional matrix that guides craniofacial growth and remodeling. A disruption in oral muscle pressure balance would therefore lead to malocclusion. For example, excessive tongue pressure against the upper front teeth can push them forward, resulting in protrusion of these teeth and increased overjet. Conversely, increased lip and cheek muscle pressure, weak tongue muscle pressure or low tongue position may contribute to the onset of posterior crossbites [7].

In spite of the popularity of this theory [8–13], literature regarding this topic is scarce. Lee et al. [9] investigated the effects of tongue and lip pressure on dentofacial morphology in 194 malocclusion patients in their 2021 study. They

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found a relationship between tongue pressure and skeletal measurements such as short posterior facial height, as well as between lip pressure and the angulation of the maxillary incisors. These findings are in agreement with prior research [8, 10, 14] although these studies did not include control groups and cheek pressure was not investigated. On the other hand, tongue pressure and position have been related to posterior crossbites [15], but the link between oral cheek pressure and posterior crossbite has not been investigated yet.

Understanding the potential effects of oral muscle pressure on growth and development can help orthodontists intercept the onset of malocclusion and optimize treatment strategies to achieve a more predictable treatment outcome. For example, myofunctional therapy could be used for early prevention of malocclusion as well as to reduce the risk of relapse following orthodontic treatment. However, the relationship between malocclusion and oral muscle pressure has not yet been objectively demonstrated.

The present study aims to evaluate the differences in lip, tongue and cheek pressure between mixed dentition patients with and without malocclusion, with a special focus on posterior crossbite and class II.

## Materials and methods

### Patient recruitment and selection criteria

The present study is a cross-sectional case-control study approved by the Ethical Committee of University Hospitals Leuven and KU Leuven University, Belgium, with registration number S54972. Patients seeking treatment at the Unit of Orthodontics of University Hospitals Leuven between November 2019 and December 2022 were screened for participation in the study.

Inclusion criteria were patients in early and late mixed dentition (from the eruption of the definitive incisors and first molars to the complete eruption of canines and premolars) with either no malocclusion (control group), posterior unilateral or bilateral crossbite (crossbite group) or class II molar relationship in combination with a class II skeletal relationship (Class II group). The crossbite group was further divided into 3 subgroups: right unilateral, left unilateral or bilateral crossbite. To be included in the crossbite group, patients needed to present a crossbite from the first definitive molar to the deciduous canine if still present, a Class I molar and canine relationship and 1–3 mm overjet and overbite. The Class II group was divided into 2 subgroups: Class II, division 1 (Class II,1) and Class II, division 2 (Class II,2). For the control group, normal occlusion was defined as Class I molar

and canine relationship, minimal crowding (< 2 mm) and 1–3 mm overjet and overbite. The occlusal parameters were clinically determined at chairside and validated on digital models afterwards.

Exclusion criteria for all groups were previous orthodontic treatment or history of facial surgery, breathing disorders, craniofacial anomalies, disorders possibly affecting perioral muscle pressure (nasal obstruction, neurological disorders or respiratory infections at the time of the measurements), inability to understand the instructions and use of medication affecting muscle activity (muscle relaxants, spasmolytics, anxiolytics).

### Oral muscle pressure data collection

Maximum lip, tongue and right and left cheek pressure were measured with the Iowa Oral Performance Instrument (IOPI, Model 2.2, Medical LLC, Carnation, WA) by different operators, following the protocol previously described by Rajbhoj et al. and Van Geneugden et al. [16–18]. All involved investigators were trained to use the appliance in the same way before taking the measurements.

### Statistical analysis

For descriptive data, comparisons between 2 groups were performed with Mann Whitney U test and comparisons between 3 or more groups were performed with Kruskal Wallis test. If variables were percentages, a chi-square test was used. To analyze group differences, linear models were used with correction for age and gender. To define the imbalance scores between different muscle pressures, z-scores were calculated for each patient for tongue, lip and cheek pressure, based on the mean and standard deviation in the control group. A positive z-score indicates higher pressure exerted by the first muscle group compared to the second; a negative z-score indicates lower pressure for the first group compared to the second. Next, the imbalance score was calculated as the difference between both z-scores. An imbalance score > 0 means that tongue pressure is larger than lip or cheek pressure, relative to other patients. An imbalance score < 0 means that tongue pressure is smaller than lip or cheek pressure. Distributional assumptions were evaluated by visual inspection of the model residuals using histograms. Since normality tests are sensitive for minor deviations of normality and linear models (such as the one applied to our data) are known to be robust against small normality deviations, Normality was not formally tested. Analyses were performed using SAS software (version 9.4 of the SAS System for Windows) and P values < 0.05 were considered significant.

## Results

A total of 146 subjects were recruited in this study, 70 in the crossbite, 41 in the Class II and 35 in the control group. Post-hoc analysis yielded a power of 0,96 for the comparison of the imbalance score between lips and tongue among the 3 groups (crossbite, class II, controls). The mean age was respectively  $8.71 \pm 0,85$ ;  $11.74 \pm 1,17$  and  $10.71 \pm 1,92$  years, which was significantly different between the three study groups ( $p < 0,001$ ), with the crossbite group presenting a lower mean age compared to the others. The study sample was unevenly split between males ( $n=76$ ) and females ( $n=70$ ), but these sex differences between groups were not significant ( $p=0.318$ ). Detailed patient characteristics are provided in Table 1.

Descriptive data of the mean maximum muscle pressure and imbalance scores per group and subgroup can be found in Table 2. Twenty-four subjects were excluded from the cheek pressure analysis due to a lack of measurements, but these patients were included for the other analyses.

Table 3 shows the comparison of the mean differences in maximum tongue, lip, cheek pressure and imbalance scores between groups. No statistically significant differences were observed between crossbite and Class II or between types of crossbite regarding tongue, lip and cheek pressure nor regarding their imbalance scores. However, when comparing crossbite and controls and Class II and controls, patients with these malocclusions showed significantly higher lip ( $p=0.004$ ,  $p=0.002$ ) and lower right ( $p=0.002$ ,  $p=0.001$ ) and left ( $p=0.003$ ,  $p=0.012$ ) cheek pressures than subjects without malocclusion. Tongue pressure was lower in patients with malocclusion but this was not significant. However, significantly different imbalance scores ( $p < 0.001$ ) indicating a lower tongue than lip pressure were found in subjects with malocclusion, although imbalance scores of tongue vs. cheek pressure were not significant between controls and subjects with malocclusion.

Significantly higher tongue pressure was found in subjects with Class II,1 compared to class II,2 ( $p=0.011$ ), but no other differences were detected. When comparing Class II,1 with controls, significantly higher maximum lip pressure ( $p=0.004$ ) and lower tongue vs. lip imbalance score (favouring the lips,  $p=0.001$ ) was found in Class II,1. In contrast, Class II,2 patients showed significantly lower tongue pressure ( $p=0.001$ ), right and left cheek pressure ( $p=0.004$  and  $0.001$ ) and tongue vs. lip imbalance score (favouring the lips,  $p=0.001$ ) compared to controls.

**Table 1** Descriptive data of the sample

Variable	All Crossbites		All Class II		Control	P value	Class II subgroups		Crossbite subgroups			P value					
	N	Mean	N	Mean			Class II,1	Class II,2	Left	Right	Bilateral						
<b>Age</b>	70	8.71	41	11.74	35	< 0.001	28	11.66	13	11.92	27	8.82	38	8.73	5	7.94	0.073
Mean		8.71		11.74	10.71		11.66		11.92		8.82		8.73		7.94		
Std		0.85		1.17	1.92		1.27		0.96		1.07		0.67		0.40		
Median		8.51		11.85	10.64		11.57		11.98		8.60		8.57		8.01		
IQR		(8.12; 9.19)		(11.01; 12.47)	(9.33; 11.67)		(10.89; 12.39)		(11.34; 12.47)		(8.01; 9.74)		(8.23; 9.19)		(7.87; 8.18)		
Range		(7.20; 11.29)		(8.67; 14.22)	(6.23; 14.92)		(8.67; 14.22)		(10.41; 13.62)		(7.20; 11.29)		(7.70; 10.52)		(7.30; 8.36)		
<b>Gender</b>																	
Female n/N (%)		35/70 (50.00%)		22/41 (53.66%)	13/35 (37.14%)	0.318	17/28 (60.71%)	5/13 (38.46%)	0.184	12/27 (44.44%)	20/38 (52.63%)	3/5 (60.00%)	0.727				
Male n/N (%)		35/70 (50.00%)		19/41 (46.34%)	22/35 (62.86%)		11/28 (39.29%)	8/13 (61.54%)		15/27 (55.56%)	18/38 (47.37%)	2/5 (40.00%)					

Note that variables presented with percentages are analysed using a Chi-square test. Variables summarized by means, medians, etc. are analysed using a Kruskal-Wallis test. All reported p-values are two-sided. Bold P-values are <0.05. Age is expressed in years

## Discussion

The present study investigates the relationship between perioral muscle pressure and malocclusion. While no differences were found between crossbite and Class II or among the crossbite types, patients with malocclusion showed significantly higher lip and lower cheek pressures and imbalance scores favouring the lips over the tongue compared to controls without malocclusion. Also, interestingly, Class II,1 patients showed significantly higher tongue pressure than Class II,2 and showed no differences in tongue or cheek pressure compared to controls. This finding refutes the assumption that increased tongue pressure causes the proclination of the upper anterior teeth, characteristic of class II,1 malocclusion, but a decreased tongue pressure may play a role in the development of Class II,2 malocclusion, since it could account for the retroclination of the upper anterior incisors typically seen in Class II,2. Thüer et al. [10] also found lip pressure on the upper incisors to be the highest in children with Class II,1 followed by Class I malocclusion and lastly by Class II, division 2 malocclusion. However, it is important to note that contrary to the study of Thüer et al., the pressure of the upper and lower lip was not individually recorded in our study, which could reveal differences between malocclusion groups (high lower lip pressure could explain retroclination of the upper anterior teeth in Class II,2 while low upper lip pressure could account for upper incisor proclination in Class II, 1). Partal et al. [19] also used IOPI to compare the perioral muscle pressure of 20 Class II,2 with 15 Class I patients. They did not find differences in muscle pressure between the groups before treatment, except for left buccal pressure which was higher in class II;2 patients. However, their study was rather focused on the effects of orthodontic protrusion of the incisors on muscle pressure change. Lee et al. [9] also examined the effects of tongue and lip pressure on dentofacial morphology with the IOPI. They found tongue pressure to be related to skeletal measurements characteristic for an open growth pattern, while lip pressure was related to the angulation of the anterior teeth.

Cheek pressure was significantly lower in malocclusion groups compared controls. This finding contradicts the hypothesis that decreased cheek pressure could account for the characteristic constriction of the maxilla of both Class II patients and patients with posterior crossbite [2]. However, we cannot compare these findings with literature, since no prior studies investigating the link between cheek pressure and posterior crossbites are available. In addition, the buccal left and right muscle pressure were compared between the subgroups right unilateral crossbite and left unilateral crossbite. The goal of this comparison was to determine whether the buccal muscle pressure is higher on the side

of the crossbite, but no significant differences were found. These findings imply that a higher cheek pressure on one side does not influence the side of the crossbite. To the best of our knowledge, no previous studies have addressed this topic, which would be interesting to study in larger sample sizes.

In our sample, patients with malocclusion also showed an imbalance between tongue and lip pressure favouring the lips. Previous studies have already argued that an imbalance in perioral muscle pressure can affect the development of malocclusion [3, 8, 11, 12]. However, no imbalance was found between tongue and cheek pressure. Since the resting position of the tongue was not evaluated in the present study, it is possible that the displacement of the tongue from its normal position in the hard palate causes buccal muscle pressure to dominate, leading to constriction of the maxilla and ultimately to a crossbite [20].

While the present study expands the knowledge on muscle imbalance and its possible role in the development of malocclusion, several limitations should be considered. First, we used the IOPI, which assesses maximum oral muscle pressure and may not be representative for the true clinical situation, as it is seldom achieved [17, 18]. These previous studies, observer correlation appeared to be good to excellent, reason why we did not calculate the Intra-class Correlation Coefficient in the present study, despite the involvement of multiple observers. However, IOPI can present high intra-and inter-individual variability [21]. Because of this, large standard variation in muscle pressure was observed, especially for the tongue. The intraoral placement of the bulb could account for this as it may vary depending on patient characteristics (e.g. age, arch dimensions, tongue mass.) [22] and on the patient's comprehension of the verbal instructions, which can be highly variable in children. Nonetheless, IOPI is a reliable instrument that avoids the need for additional laboratory processes. Other methods to measure perioral muscle pressure include Force Sensing Resistors (FSRs), strain gauges, pressure transducers, manometry and electromyography [9, 23–27]. However, objective assessment of oral muscle pressure in rest and during function, especially what regards intraoral muscles, remains challenging. For example, the use of standardized surface electromyography to assess perioral muscle pressure depends on the stability of the occlusal plane, since recordings are made with the patient's teeth in contact, which can be a problem in mixed dentition [23].

Secondly, we did not record the possible oral dysfunctions of our patient population, such as tongue position, lower lip interposition, swallowing pattern, nail biting or bruxism. Research has shown that oral dysfunction (in particular tongue position and lower lip interposition) can contribute to the development of malocclusion. An incorrect

**Table 2** Descriptive data of the mean muscle pressure in kilopascal values per group and subgroup

Variable		Crossbite	Class II	Control	Class II subgroups		Crossbite subgroups		
					Class II,1	Class II,2	Left	Right	Bilateral
<b>Tongue</b>	N	70	41	35	28	13	27	38	5
	Mean	32.09	33.73	37.57	36.32	28.15	31.70	31.74	36.80
	Std	11.749	10.950	8.237	10.576	9.932	12.338	11.705	9.731
	Median	29.50	33.00	37.00	35.00	27.00	30.00	29.00	40.00
	IQR	(22.00; 41.00)	(26.00; 40.00)	(31.00; 41.00)	(29.50; 43.50)	(20.00; 34.00)	(21.00; 39.00)	(22.00; 41.00)	(27.00; 44.00)
	Range	(11.00; 59.00)	(16.00; 57.00)	(26.00; 61.00)	(16.00; 57.00)	(17.00; 49.00)	(11.00; 57.00)	(11.00; 59.00)	(26.00; 47.00)
<b>Lips</b>	N	70	41	35	28	13	27	38	5
	Mean	13.40	14.20	10.77	14.57	13.38	13.48	13.42	12.80
	Std	4.261	5.302	2.658	6.027	3.305	4.032	4.665	2.387
	Median	12.00	14.00	10.00	13.50	15.00	14.00	12.00	13.00
	IQR	(10.00; 16.00)	(11.00; 16.00)	(9.00; 13.00)	(11.50; 16.00)	(11.00; 16.00)	(10.00; 17.00)	(11.00; 16.00)	(11.00; 14.00)
	Range	(6.00; 32.00)	(7.00; 37.00)	(6.00; 19.00)	(7.00; 37.00)	(8.00; 17.00)	(6.00; 22.00)	(8.00; 32.00)	(10.00; 16.00)
<b>Left cheek</b>	N	46	41	35	28	13	19	23	4
	Mean	16.22	17.98	20.74	18.61	16.62	16.32	16.17	16.00
	Std	4.830	5.150	3.928	5.391	4.482	4.607	5.416	2.708
	Median	16.00	18.00	20.00	19.00	17.00	16.00	16.00	15.00
	IQR	(14.00; 19.00)	(14.00; 21.00)	(18.00; 23.00)	(14.00; 22.00)	(14.00; 20.00)	(13.00; 19.00)	(14.00; 20.00)	(14.50; 17.50)
	Range	(6.00; 28.00)	(8.00; 31.00)	(14.00; 32.00)	(10.00; 31.00)	(8.00; 23.00)	(9.00; 28.00)	(6.00; 26.00)	(14.00; 20.00)
<b>Right cheek</b>	N	46	41	35	28	13	19	23	4
	Mean	15.43	18.02	20.46	18.79	16.38	16.32	15.30	12.00
	Std	4.559	4.204	3.705	4.442	3.203	4.282	4.940	1.414
	Median	15.00	18.00	20.00	19.00	16.00	18.00	15.00	11.50
	IQR	(12.00; 19.00)	(15.00; 20.00)	(18.00; 23.00)	(15.00; 22.00)	(16.00; 19.00)	(14.00; 19.00)	(12.00; 20.00)	(11.00; 13.00)
	Range	(7.00; 25.00)	(8.00; 28.00)	(13.00; 31.00)	(12.00; 28.00)	(8.00; 20.00)	(8.00; 22.00)	(7.00; 25.00)	(11.00; 14.00)
<b>Delta_z Tongue-Lip</b>	N	70	41	35	28	13	27	38	5
	Mean	-1.66	-1.75	-0.00	-1.58	-2.13	-1.73	-1.71	-0.86
	Std	2.137	2.160	0.998	2.294	1.867	2.171	2.226	1.206
	Median	-1.51	-1.50	0.04	-1.19	-2.02	-1.77	-1.50	-0.82
	IQR	(-2.60; -0.14)	(-2.70; -0.29)	(-0.67; 0.60)	(-2.67; 0.04)	(-3.60; -1.37)	(-3.48; -0.22)	(-2.94; -0.05)	(-1.49; -0.06)
	Range	(-8.18; 2.92)	(-9.09; 2.43)	(-2.62; 2.30)	(-9.09; 1.19)	(-4.84; 2.43)	(-6.24; 2.92)	(-8.18; 2.89)	(-2.50; 0.59)
<b>Delta_z Tongue-Left cheek</b>	N	46	41	35	28	13	19	23	4
	Mean	0.39	0.24	0.00	0.39	-0.09	0.28	0.37	1.02
	Std	1.855	1.556	1.102	1.696	1.193	1.911	1.948	1.124
	Median	0.43	0.21	-0.01	0.25	-0.30	0.31	0.42	0.70
	IQR	(-0.72; 1.64)	(-0.61; 0.87)	(-0.77; 0.96)	(-0.55; 1.08)	(-1.01; 0.87)	(-1.05; 1.82)	(-0.72; 1.23)	(0.24; 1.79)
	Range	(-3.74; 4.64)	(-3.89; 4.84)	(-1.86; 1.94)	(-3.89; 4.84)	(-1.80; 1.77)	(-3.74; 3.50)	(-2.74; 4.64)	(0.06; 2.61)
<b>Delta_z Tongue-Right cheek</b>	N	46	41	35	28	13	19	23	4
	Mean	0.59	0.19	0.00	0.30	-0.04	0.27	0.59	2.09
	Std	1.942	1.459	1.151	1.544	1.284	2.103	1.794	1.659
	Median	0.49	0.22	-0.00	0.30	-0.04	0.31	0.54	2.11
	IQR	(-0.75; 1.82)	(-0.89; 1.04)	(-0.80; 0.88)	(-0.86; 1.05)	(-1.02; 0.99)	(-1.50; 1.40)	(-0.20; 1.82)	(0.67; 3.52)
	Range	(-2.67; 4.72)	(-2.27; 4.64)	(-2.05; 2.15)	(-2.27; 4.64)	(-2.01; 2.05)	(-2.67; 4.72)	(-2.67; 3.97)	(0.46; 3.70)

**Table 3** Comparison of the mean difference in maximum tongue, lip, cheek pressure and imbalance scores between groups

Comparison	Imbalance scores																				
	Pressure			Lip			Left cheek			Right cheek			Tongue vs. Lip			Tongue vs. Left cheek			Tongue and Right cheek		
	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	Mean difference (95% CI)	P-value	
<b>Class II vs. Crossbite</b>	0.18 (-5.82;6.18)	0.951	-0.35 (-2.73;2.02)	0.768	-0.32 (-3.08;2.45)	0.820	0.60 (-1.87;3.07)	0.631	0.16 (-0.92;1.23)	0.775	0.17 (-0.77;1.10)	0.722	-0.07 (-1.02;0.87)	0.877							
<b>Class II vs. Control</b>	-4.17 (-9.35;1.00)	0.113	2.99 (0.94;5.03)	<b>0.004</b>	-3.48 (-5.71;-1.24)	<b>0.003</b>	-3.17 (-5.16;-1.17)	<b>0.002</b>	-1.63 (-2.56;-0.70)	<b>0.001</b>	0.36 (-0.40;1.12)	0.347	0.33 (-0.43;1.10)	0.393							
<b>Crossbite vs. Control</b>	-4.36 (-9.62;0.91)	0.104	3.34 (1.26;5.42)	<b>0.002</b>	-3.16 (-5.60;-0.72)	<b>0.012</b>	-3.77 (-5.94;-1.59)	<b>0.001</b>	-1.79 (-2.73;-0.84)	<b>0.000</b>	0.19 (-0.63;1.02)	0.645	0.41 (-0.43;1.24)	0.338							
<b>Class II,1 vs. Class II,2</b>	8.38 (2.00;14.77)	<b>0.011</b>	-1.28 (-5.07;2.51)	0.498	-2.10 (-5.75;1.55)	0.251	-2.59 (-5.49;0.31)	0.079	-0.56 (-2.11;0.99)	0.469	-0.50 (-1.62;0.61)	0.364	-0.34 (-1.39;0.71)	0.514							
<b>Class II,1 vs. Control</b>	-2.36 (-7.40;2.69)	0.355	3.47 (1.16;5.78)	<b>0.004</b>	-2.45 (-4.92;0.03)	0.052	-1.91 (-4.01;0.18)	0.073	-1.59 (-2.53;-0.66)	<b>0.001</b>	0.34 (-0.40;1.08)	0.367	0.23 (-0.49;0.95)	0.525							
<b>Class II,2 vs. Control</b>	-10.74 (-17.06;-4.41)	<b>0.001</b>	2.11 (-0.79;5.00)	0.151	-4.63 (-7.74;-1.53)	<b>0.004</b>	-4.54 (-7.17;-1.91)	<b>0.001</b>	-2.10 (-3.27;-0.92)	<b>0.001</b>	-0.12 (-1.05;0.80)	0.790	-0.08 (-0.98;0.83)	0.863							
<b>Left vs. Right Crossbite</b>	-0.25 (-6.22;5.72)	0.933	0.10 (-2.10;2.30)	0.930	0.62 (-2.34;3.58)	0.676	1.79 (-0.86;4.43)	0.180	-0.07 (-1.15;1.02)	0.901	-0.37 (-1.51;0.77)	0.515	-0.70 (-1.84;0.44)	0.225							
<b>Left vs. Bilateral Crossbite</b>	-4.65 (-16.55;7.25)	0.438	0.55 (-3.84;4.94)	0.804	-1.53 (-6.80;3.73)	0.560	2.82 (-1.88;7.52)	0.232	-0.77 (-2.93;1.39)	0.479	-0.18 (-2.21;1.84)	0.858	-1.33 (-3.36;0.69)	0.192							
<b>Right vs. Bilateral Crossbite</b>	-4.39 (-15.95;7.16)	0.450	0.45 (-3.81;4.72)	0.833	-2.15 (-7.41;3.11)	0.414	1.04 (-3.66;5.73)	0.658	-0.70 (-2.80;1.39)	0.505	0.19 (-1.83;2.21)	0.851	-0.64 (-2.66;1.39)	0.529							

Abbreviations CI: confidence interval. Note that differences between the groups were analyzed with linear models with correction for age and gender. Positive mean pressure differences refer to higher pressure for the first group. Positive imbalance scores mean that tongue pressure is larger than lip or cheek pressure. The analysis is corrected for age and gender. Bold P-values refer to < 0



tongue posture may play a role in the onset of a posterior crossbite, while lower lip interposition may influence mandibular growth may play a role in the onset of malocclusion. [11, 28–30]

It is also important to consider that z-scores rely on the control group to be ‘in balance’, since they describe whether a given measurement lies below or above the mean of the control group [24]. Finally, we did not record repeated measurements and therefore measurement error was not analyzed. However, the error of the IOPI methodology has been published in several prior studies [25, 26].

In spite of these limitations, our study also has several strengths. First, it includes a control group of patients without malocclusion, which is not easy to find in literature. This reduces bias and confounding factors that could affect the results of the study. Second, the statistical analysis is corrected for age and gender, which is especially important with regards to oral muscle pressure, since it increases with age and is different between men and women [3, 27]. This also allowed us to overcome the significant difference in age between groups found in our sample. Also, recent clinical studies found that oral function develops significantly during the mixed dentition phase [28, 31]. Therefore, our study sample consists of patients in mixed dentition as intervening during this stage of development would be ideal. We chose to focus on Class II malocclusion and posterior crossbite as these are two of the most prevalent types of malocclusion, normally intercepted during mixed dentition.

Investigating the role of oral muscle dysfunction in the development of malocclusion has important clinical implications for its early prevention, to predict treatment outcomes and to prevent relapse after orthodontic treatment. For instance, the assessment of oral muscle pressure could be included in the routine diagnostic and post-treatment records, which would help adapting the orthodontic treatment strategy and the retention protocol. Another example could be the inclusion of myofunctional therapy in the prevention and treatment of malocclusion, potentially improving muscle strength, function and imbalance, ultimately influencing tooth position and maxillary growth. However, it is important to acknowledge that malocclusion is a multifactorial condition, and the influence of oral muscle pressure on its development remains undefined and may only partially explain its onset [12, 29–33].

## Conclusion

This cross-sectional study suggests an association between oral muscle pressure and malocclusion. Patients with malocclusion (Class II and crossbite) showed significantly higher lip and lower cheek pressure and imbalance scores

favouring the lips over the tongue compared to controls without malocclusion. Class II,1 patients showed significantly higher tongue pressure than Class II,2 and showed no differences in tongue or cheek pressure compared to controls. No differences were found in muscle pressure or in imbalance between crossbite and Class II nor between crossbite types. These findings highlight the importance of functional diagnosis in orthodontics and may have important implications for malocclusion prevention, orthodontic treatment planning and outcome stability.

**Acknowledgements** The authors would like to thank Annouschka Laenen, from the Interuniversity Institute for Biostatistics (L-Biostat) of the University of Hasselt, Belgium, for the Statistic Analysis.

**Author contributions** - L.D., S.V. and A.A.R.: Investigation, Conceptualization, Methodology, Data Curation, Review & Editing- M.C.: Writing, Visualization, Supervision- G.B., G.W., A.V.: Review & Editing, Visualization All authors have read and agreed to the published version of the manuscript.

**Funding** This research received no external funding.

**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Ethics approval and consent to participate** Informed consent was obtained from all subjects involved in the study.

**Conflict of interest** The authors declare no conflict of interest.

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