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Bite and Sight: Is There a Correlation? Clinical Association between Dental Malocclusion and Visual Disturbances in Pediatric Patients

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Abstract: Aim: The aim of this study was to evaluate the correlation between malocclusions and visual defects. This is a case-control study evaluating the prevalence of visual defects in patients with different types of malocclusions. Methods: One-hundred and sixty patients aged from 5 to 14 were evaluated using the ROMA index to detect malocclusion; the ones with the lowest scores were used as the control group. They were also submitted to visual-capacity inspection for motility and refractive disorders. Results: Our work showed an enhanced prevalence of refractive defects or fusional vergence defects and alteration of eye movements (especially the saccades) in almost all dental malocclusions. Statistics: The Kappa test values for ROMA index were between 0.643 and 1.00 for the intraoperator agreement ($0.00 < p < 0.002$) and between 0.773 and 1.00 for the agreement between operators ($p = 0 < 0.001$). The statistically significance level for the correlation malocclusion/visual defects was set at $p < 0.05$. Statistical analyses were performed with the STATA software (version 15.0, Stata Corp LP, College Station, TX, USA). Conclusion: Considering the high level of the statistical analysis and the accuracy of the methodology used, these data allows the establishment of a huge correlation between sagittal, transversal and vertical malocclusions with ocular disorders (myopia, hyperopia, astigmatism and ocular motility defects).

Keywords: dental malocclusions; visual disturbances; pediatric patients; refractive defects; alteration eye movements; ROMA index

1. Introduction

Anatomic systems are organized through a network of structural and functional relationships between their elements. This network of relationships generates a set of rules that guide and constrain morphogenetic processes. Decades of investigations have shown that craniofacial development is an intricate and complex series of events that results in the correct outgrowth, patterning and tissue integration, required to make a face [1]. The soft tissue matrix—in which skeletal elements are embedded—is the primary determinant of growth, while both the bone and cartilage are reactive secondary growth sites. This is the fundamental premise of the functional matrix theory [2].

The embryonic facial maxillary prominences develop numerous intramembranous ossification centers. One of them is the orbito-nasal center that starts formation around the seventh week. The eye,

nasal cavity, maxilla and external ear act as functional matrices, influencing each other under a sophisticated mechanism. The orbits complete half the postnatal growth during the first two years and attain adult dimensions around seven years of age. During this period, the growth of the maxilla is related to orbit development, and vice versa; maxilla growth depends on several functional matrices, including correct mouth functioning [3].

The relationship between occlusion, the masticatory muscle system and head posture have recently been confirmed. Several studies have supported the anatomic connection between the stomatognathic system and ocular systems [4]. Since the maxilla has interface with all the bones that form the orbit, untreated malocclusions can lead to visual problems. Visual problems can also lead to altered mandible posture [5]. It is also extremely important to understand the close relation of the trigeminal system and the oculomotor system. Wrong afferences of one system can alter the efferences in both [6]. The central nervous system integrates proprioception (including mandible proprioceptors) and other sensory systems, such as vision and the vestibular system, to create an overall representation of body position, movement and acceleration [7]. If a situation of altered muscular tension arises in one part of the chain (mandible, hyoid, vertebrae, pelvis and limbs), there will be a loss of equilibrium, giving rise to compensatory mechanisms. Alteration of mandible position can cause temporary alteration of the position of the pupillary line, leading the eye muscles to intervene in order to keep the eyes straight [8]. In fact, to follow an object's movement, the eye must be able to coordinate the movement of the head and neck [9].

Eye-motility disorders are highly prevalent. When musculature fails to maintain the eye position during focusing, we can have exophoria—if the eyes deviate outward. We have esophoria if they deviate inward. We also can have a permanent deviation called strabismus [10]. Strabismus is a condition in which the visual axes of the eyes are not parallel, and the eyes seem to look in different directions. The general prevalence of strabismus is about 5% for any age after six years [11]. These are the most common motility disorders. There is a strong correlation among their prevalence and head posture, body posture and malocclusions [12]. We also must remember that human beings have eye dominance; when the preference of one eye is enhanced, there is a tendency to move the head to the opposite side of dominant eye and consequently to move the mandible to the dominant eye side, in order to get postural compensation [6]. Due to this, we can make the following statements to understand the connection between trigeminal and oculomotor system and its relation with body posture:

(1)   Mandibular displacement can cause an adaptation in the position of the head;
(2)   Ocular phorias can cause a head-compensating posture even generating torticollis;
(3)   Position of the head is a key point in the body balance to maintain a center of gravity compatible with the standing position [13,14].

Hence, the interconnection between stomatognathic system and vision comes from the morphologic aspect to the functional one. Morphologic changes of orbit shape can make the individual more prone (acting as epigenetic factors) to other common visual problems like Myopia, Hyperopia and Astigmatism [5,15].

Myopia is a visual defect where the ocular globe is elongated and the image forms before the retina. Prevalence rates range from about 30% in middle-aged adults and from 35% to 37% in young adults. Malocclusions can enhance prevalence of Myopia [16].

Hypermetropia or Hyperopia is an eye condition in which incoming light rays reach the retina before converging into a targeted image. It can happen due to sagittal shortening of ocular globe. The prevalence of hypermetropia is not clear. It runs from 9.9%, to 28.9%. [17]

Astigmatism is a common vision condition that causes blurred vision. It occurs when the cornea (the clear front cover of the eye) is irregularly shaped or sometimes because of the curvature of the lens inside the eye. Racial variations influence the prevalence and the degree of astigmatism. The alteration of orbit shape can lead to an enhancement of cornea curvature [18].

As shown above there are many studies discussing the prevalence of vision defects in the general population and it is also possible to find some works correlating vision defects with different types of alterations of maxilla/mandible relation. Malocclusion is a highly prevalent condition and it can disturb this relation in different directions; sagittal, vertical and transversal. Considering that, the objective of this study was to reinforce the concept of a correlation between visual defects and dentoskeletal malocclusions in a sample of growing patients, evaluating the maxilla/mandible relations of the three planes. In addition, since vision and occlusion are important afferences to establish a body posture, we also investigated body posture compensations of the sample.

2. Materials and Methods

The study was conducted in accordance with the Declaration of Helsinki and the protocol was approved by the Ethics Committee of the University of L'Aquila (Document DR206/2013, 16 July 2013). This retrospective clinical study was conducted on 216 patients (104 male subjects and 112 female subjects) of the Ophthalmology Clinic of the Head–Neck Department, between September 2018 and June 2019. A total of 55 patients were excluded for presenting other visual defects, history of orthodontic treatment and past extraction of permanent teeth. The remaining 160 subjects (76 male and 84 female) were included in the study. The age between 5 and 14 years, average age 10 years (SD 3). The patients were all submitted to an ophthalmologic and orthoptic examination for evaluation of: Myopia, Hypermetropia (Hyperopia), Astigmatism, Strabismus, Latent strabismus, Manifested strabismus, fusional vergence, saccadic eye movements and smooth pursuit movements. The orthoptic examination was performed through the following tests: Cover/uncover test; cover test with prism; Convergence; fusional amplitude, Northeastern State University College of Optometry (NSUCO) test. It gives precise values to the observations made by the clinician. (See in—Appendix A). The orthodontic conditions were classified as follows: sagittal, vertical and transversal malocclusions, according to the Risk Of Malocclusion Assessment (ROMA) Index [19] that distinguishes the problems of the three level of malocclusions, crowding and spoiled habits (nonnutritive suction, bruxism and oral breathing). (Appendix B—Table A1). Dental exam was performed by two dentists (CR and FA). The ROMA index was evaluated by operators who have previously undergone a one-month training period following the instructions in a specific manual, in order to apply the index with the same standard of judgment and to minimize errors. Furthermore, the index has already been validated and its intraoperator and interoperator reproducibility was verified. The orthoptic exam and the ophthalmic examination was executed by two ortoptist (VC and EDN), in order to eliminate inter-examiner differences and examiner bias.

Statistic Analysis

The vision situation of the sample, stratified for orthodontic condition, was compared to a control group (no malocclusions). Descriptive statistics, such as frequencies with percentages, was used to examine the characteristics of the sample. Statistical significance of differences between each orthodontic group and the control group was analyzed using χ^2 test.

To verify the potential association between each of the analyzed vision defects, chosen as dependent variables, and the various categories of malocclusion, univariate logistic regression models were used, with associations reported as odds ratios (ORs) and 95% confidence intervals (CIs). The absence of each specific malocclusion was chosen as reference category (e.g., the reference category for the Class II malocclusion in each regression model was the absence of this orthodontic condition). Factors with a *p*-value of less than 0.05 in univariate models were included in the multivariate logistic regression models, to identify independent associations, with ORs adjusted for the other factors in the models. The statistically significant level was set at $p < 0.05$.

The statistical analysis was performed with the STATA software (version 15.0, Stata Corp LP, College Station, TX, USA).

The power of the study was evaluated using Pearson's chi-squared test comparing two independent proportions: presence of astigmatism in the control group ($n = 52$) and in subjects with malocclusions ($n = 108$) (11% vs. 31%). The estimated power (1-β) was 82%.

3. Results

A total of 160 subjects (76 male and 84 female) were included in the study:

- 52 (32.50%, 52/160) patients had no malocclusions (Group "0"—control group). Vision defects was detected in 50.98% of them;
- 61 (38.13%, 61/160) patients showed sagittal malocclusions, 52 (32.50%, 52/160) showed Class II, 9 (5.63%, 9/160) showed Class III;
- 51 (31.88%, 51/160) patients showed vertical malocclusions, 36 (22.50%, 36/160) showed deep bite and 15 (9.38%, 15/160) an open bite;
- 34 (21.25%, 34/160) patients showed transversal malocclusion with a presence of cross bite.

We observed the results obtained by the following groups (Table 1).

- **Sagittal malocclusions**

  - **Class II.** The presence of sight defects was detected in 40.38% of the subjects. Higher percentages were found for almost all visual defects compared to the control group. In particular, children with myopia were more than twice (61.54% vs. 23.53%, $p < 0.001$) that of the control group, and children with latent or manifested strabismus were almost four or three times more represented, respectively (40.38% vs. 11.54%, $p < 0.01$; 36.54% vs. 11.54%, $p < 0.01$, respectively). A tracking defect was found in 42.31% of children compared to 21.57% of the control group ($p < 0.001$) and an alteration in the tracking precision was detected in 40.38% (vs. 17.31%, $p < 0.001$). The percentage of children with strong compensation of the body and head was greater than the control group (40.38% vs. 15.38%, $p < 0.01$).
  - **Class III.** The presence of vision defects was detected in 44.44% of the subjects. Children with astigmatism, latent or manifested strabismus were almost five times more represented than in the control group (55.56% vs. 11.54%, $p < 0.01$). A tracking defect and an alteration in the tracking precision were found in 55.56% of children compared to 21.57% and 17.31%, respectively, of the control group ($p < 0.001$ and $p < 0.01$, respectively). The percentage of children with strong compensation of the body and head was greater than the control group (55.56% vs. 15.38%, $p < 0.01$).

- **Vertical malocclusions**

  - **Deep bite.** The presence of vision defects was detected in 51.43% of the subjects. Significantly higher percentages than those in the control group were found for hyperopia (40.00% vs. 17.65%, $p < 0.001$) and manifested strabismus (40.00% vs. 17.65%, $p < 0.01$);
  - **Open bite.** The presence of vision defects was detected in 53.33% of the subjects. Children with astigmatism were four times more represented than in the control group (46.67% vs. 11.54%, $p < 0.01$).

- **Transversal malocclusions**

  - **Cross bite**. The presence of vision defects was detected in 45.45% of the subjects. Children with myopia or hyperopia were significantly less numerous than those in the control group (2.95% vs. 23.53%, $p < 0.001$ and 2.94% vs. 17.65%, $p < 0.001$, respectively). On the contrary, children with astigmatism (50.00% vs. 11.54%, $p < 0.05$) or latent and manifested strabismus (38.24% vs. 11.54%, $p < 0.01$) were more represented than in the control group. The percentage of subjects with strong compensation of the body and head was greater than the control group (38.24% vs. 15.38%, $p < 0.01$).

Table 1. Frequency distributions of vision defects, stratified for orthodontic condition.

Type of Visual Defects	Total	Control Group	Class II	Class III	Deep Bite	Open Bite	Cross Bite
	(*n* = 160)	(*n* = 52)	(*n* = 52)	(*n* = 9)	(*n* = 36)	(*n* = 15)	(*n* = 34)
Myopia, *n* (%)							
Absent	102 (64.97)	39 (76.47)	20 (38.46)	8 (88.89)	20 (58.82)	9 (60.00)	33 (97.06)
Present	55 (35.03)	12 (23.53)	32 (61.54) *	1 (11.11) °	14 (41.18) °	6 (40.00) °	1 (2.94) ***
Astigmatism, *n* (%)							
Absent	119 (74.84)	46 (88.46)	41 (78.85)	4 (44.44)	29 (82.86)	8 (53.33)	17 (50.00)
Present	40 (25.16)	6 (11.54)	11 (21.15) °	5 (55.56) **	6 (17.14) °	7 (46.67) **	17 (50.00) *
Hyperopia, *n* (%)							
Absent	123 (77.85)	42 (82.35)	43 (82.69)	8 (88.89)	21 (60.00)	10 (66.67)	33 (97.06)
Present	35 (22.15)	9 (17.65)	9 (17.31) °	1 (11.11) °	14 (40.00) ***	5 (33.33) °	1 (2.94) ***
Latent strabismus, *n* (%)							
Absent	117 (73.58)	46 (88.46)	31 (59.62)	4 (44.44)	25 (71.43)	13 (86.67)	21 (61.76)
Present	42 (26.42)	6 (11.54)	21 (40.38) **	5 (55.56) **	10 (28.57) °	2 (13.33) °	13 (38.24) **
Manifested strabismus, *n* (%)							
Absent	116 (72.96)	46 (88.46)	33 (63.46)	4 (44.44)	21 (60.00)	13 (86.67)	21 (61.76)
Present	43 (27.04)	6 (11.54)	19 (36.54) **	5 (55.56) **	14 (40.00) **	2 (13.33) °	13 (38.24) **
Saccadic ability, *n* (%)							
Absent	98 (61.64)	29 (55.77)	30 (57.69)	4 (44.44)	23 (65.71)	12 (80.00)	21 (61.76)
Present	61 (38.36)	23 (44.23)	22 (42.31) °	5 (55.56) °	12 (34.29) °	3 (20.00) °	13 (38.24) °
Tracking ability, *n* (%)							
Absent	109 (68.99)	40 (78.43)	30 (57.69)	4 (44.44)	22 (62.86)	12 (80.00)	23 (67.65)
Present	49 (31.01)	11 (21.57)	22 (42.31) ***	5 (55.56) ***	13 (37.14) °	3 (20.00) °	11 (32.35) °
Saccadic precision, *n* (%)							
Absent	111 (69.81)	40 (76.92)	31 (59.62)	4 (44.44)	25 (71.43)	11 (73.33)	22 (64.71)
Present	48 (30.19)	12 (23.08)	21 (40.38) °	5 (55.56) °	10 (28.57) °	4 (26.67) °	12 (35.29) °
Tracking precision, *n* (%)							
Absent	115 (72.33)	43 (82.69)	31 (59.62)	4 (44.44)	25 (71.43)	12 (80.00)	22 (64.71)
Present	44 (27.67)	9 (17.31)	21 (40.38) ***	5 (55.56) **	10 (28.57) °	3 (20.00) °	12 (35.29) °
Mov Head/body, *n* (%)							
Absent	117 (73.58)	44 (84.62)	31 (59.62)	4 (44.44)	27 (77.14)	12 (80.00)	21 (61.76)
Present	42 (26.42)	8 (15.38)	21 (40.38) **	5 (55.56) **	8 (22.86) °	3 (20.00) °	13 (38.24) **
Visual defects, *n* (%)							
Absent	74 (47.13)	26 (50.98)	21 (40.38)	4 (44.44)	18 (51.43)	8 (53.33)	15 (45.45)
Present	83 (52.87)	25 (49.02)	31 (59.62) °	5 (55.56) °	17 (48.57) °	7 (46.67) °	18 (54.55) °

Statistical significance of frequency distributions compared to the control group using χ^2 test: * $p < 0.001$, ** $p < 0.01$, *** $p < 0.05$, ° $p \geq 0.05$.

Univariate and multivariate logistic regression models (see Table 2) demonstrated that Class II malocclusions resulted independently associated with myopia (OR 5.68, 95% CI 2.58–12.49, $p < 0.001$); on the contrary, myopia was less likely if cross bite malocclusion was present (OR 0.04, 95% CI 0.005–0.30, $p = 0.002$). Cross bite emerged as a risk factor for astigmatism (OR 3.93, 95% CI 1.67–9.25, $p = 0.002$); on the contrary, hyperopic vision was less likely to occur with cross bite malocclusion (OR 0.10, 95% CI 0.01–0.81, $p = 0.031$). Class II malocclusion emerged as a risk factor also for latent strabismus (OR 2.77, 95% CI 1.34–5.76, $p = 0.006$), defect of tracking ability (OR 2.15, 95% CI 1.06–4.33, $p = 0.033$) and tracking precision (OR 2.47, 95% CI 1.20–5.09, $p = 0.014$) and for compensation of the body and head (OR 2.77, 95% CI 1.34–5.76, $p = 0.006$). (See Table 2).

Table 2. Univariate and multivariate logistic regression analysis for the association between vision defects and orthodontic condition.

	Univariate Logistic Regression			Multivariate Logistic Regression		
	OR	95% CI	*p*-Value	OR °	95% CI	*p*-Value
MYOPIA						
Class II	5.70	2.76–11.78	<0.001	5.68	2.58–12.49	<0.001
Class III	0.22	0.03–1.79	0.156			
Deep bite	1.40	0.64–3.05	0.397			
Open bite	1.27	0.43–3.76	0.672			
Cross bite	0.04	0.005–0.29	0.002	0.04	0.005–0.30	0.002
ASTIGMATISM						
Class II	0.72	0.33–1.59	0.418			
Class III	4.11	1.05–16.13	0.043	1.93	0.43–8.59	0.387
Deep bite	0.55	0.21–1.44	0.221			
Open bite	2.94	0.99–8.72	0.051			
Cross bite	4.43	1.97–9.97	<0.001	3.93	1.67–9.25	0.002
HYPEROPIA						
Class II	0.64	0.28–1.50	0.307			
Class III	0.42	0.05–3.50	0.425			
Deep bite	3.24	1.42–7.38	0.005	2.30	0.99–5.33	0.052
Open bite	1.88	0.60–5.93	0.279			
Cross bite	0.08	0.01–0.61	0.015	0.10	0.01–0.81	0.031
LATENT STRABISMUS						
Class II	2.77	1.34–5.76	0.006			
Class III	3.82	0.97–14.97	0.055			
Deep bite	1.15	0.50–2.65	0.743			
Open bite	0.40	0.09–1.85	0.241			
Cross bite	2.05	0.91–4.59	0.081			
MANIFESTED STRABISMUS						
Class II	1.99	0.96–4.11	0.062			
Class III	3.68	0.94–14.43	0.061			
Deep bite	2.18	0.99–4.83	0.054			
Open bite	0.39	0.08–1.79	0.224			
Cross bite	1.96	0.88–4.38	0.101			
SACCADIC ABILITY						
Class II	1.28	0.65–2.52	0.476			
Class III	2.10	0.54–8.14	0.284			
Deep bite	0.80	0.36–1.75	0.575			
Open bite	0.37	0.10–1.37	0.137			
Cross bite	0.99	0.46–2.17	0.986			
TRACKING ABILITY						
Class II	2.15	1.06–4.33	0.033			
Class III	2.98	0.76–11.63	0.116			
Deep bite	1.43	0.65–3.14	0.376			
Open bite	0.53	0.14–1.96	0.339			
Cross bite	1.08	0.50–2.44	0.849			
SACCADIC PRECISION						
Class II	2.01	0.99–4.06	0.053			
Class III	3.11	0.80–12.14	0.102			
Deep bite	0.91	0.40–2.07	0.813			
Open bite	0.83	0.25–2.74	0.755			
Cross bite	1.35	0.60–3.01	0.465			
TRACKING PRECISION						
Class II	2.47	1.20–5.09	0.014			
Class III	3.56	0.91–13.92	0.068			
Deep bite	1.06	0.46–2.43	0.893			
Open bite	0.63	0.17–2.34	0.488			
Cross bite	1.59	0.71–3.56	0.265			
MOV. HEAD/BODY						
Class II	2.77	1.34–5.76	0.006			
Class III	3.82	0.97–14.97	0.055			
Deep bite	0.78	0.32–1.89	0.589			
Open bite	0.67	0.18–2.51	0.556			
Cross bite	2.05	0.91–4.59	0.081			

° odds ratio (OR) adjusted for other factors in the model.

4. Discussion

The purpose of this study was to highlight the relationship between the visual system and the stomatognathic system. Some authors have published interesting works about this subject but have generally focused on one malocclusion condition or another [5,15]. Our work brings a comprehensive correlation of different ocular disorders and malocclusions presented in the sagittal, transversal and vertical planes. We tried to clarify for the health community the importance of understanding the human being not in a compartmentalized state, but as an integrated group of systems that communicate each other. Problems that occur in the visual system can result in consequences of imbalances in the stomatognathic system or vice versa. It was also emphasized the relevance of including oculist–orthoptic exams of the protocol of stomatognathic system evaluation, to support preventive interventions in a pediatric population. Our work showed an enhanced prevalence of refractive defects, fusional vergence defects and alteration saccadic eye movements and pursuit movements, in almost all dental malocclusions. These findings can be reinforced by the results presented in a study that demonstrate the improvement of symmetry in the orbital and maxillary regions in patients after rapid maxillary expansion [20]. In sagittal malocclusions, refractive defect myopia were found in 61.54% of the patients presenting Class II malocclusion, while control group showed 23.53% of prevalence. They also presented alterations of the ability of saccadic movements two times bigger than control group. Caruso had also demonstrated a statistically significant association between Class II and the occurrence of exodeviations, associating occlusal molar Class II to fusional vergence defects [21]. In relation to refractive vices we are in agreement with Monaco et al. as they found a greater prevalence of refractive defects in patients with sagittal malocclusions too [22]. However, the higher prevalence of strabismus in the Class II group found in our sample, where children with latent or manifested strabismus were almost four or three times more represented, (40.38% vs. 11.54%, $p < 0.01$; 36.54% vs. 11.54%, $p < 0.01$, respectively), is not in accord to Monaco work, since they did not find an enhancement in the vergence capacity. It indicates that further investigations are necessary, expanding the sample examined, to be able to demonstrate and better understand this divergence of results. For Class III patients we found a huge statistical difference (5 times more) in the prevalence of astigmatism and strabismus. It was interesting to note from our results that the values of a fusional amplitude below the normal range and an alteration of the abilities of saccadic movements presented themselves with very similar percentages in almost all malocclusions. It is also important to highlight that body compensations presented by patients with sagittal malocclusions were three times bigger when compared to the control group. Many works had demonstrated that vision influences body posture and also there is a correlation between mandibular position and body posture [23–27]. In our sample is impossible to determine if the malocclusions generated a body compensation, if the visual problem was the cause of it or if both were related to the observed increase in posture alteration. Specific design of investigation must be done to clarify this finding.

Patients with transverse malocclusion or crossbite have refractive defects almost exclusively represented by astigmatism. The prevalence was almost five times bigger than control. The group also showed a prevalence of strabismus three times bigger than control, showing alteration in the saccades ability. Referring to astigmatism, we are in accord to with Monaco [22]. In their study they have specifically reported statistically significant correlations between astigmatism and crossbite. In our data we also find body compensation in a high prevalence (more than two times compared to the control) in patients presenting crossbites. The relationship between Strabismus and malocclusion was investigated by Giuca et al. [28]. They found a slightly increase of cross bite in the group of subjects with strabismus, but not statistically significant. Malocclusion is a multifactorial condition of multiple features for which is difficult to demonstrate a cause–effect relationship. In our results we found a significance of the presence of cross bite in children with strabismus. Therefore, this relationship deserves to be investigated further [28].

In patients with vertical malocclusions, refractive errors were found in 75% of patients with a deep bite and in 68% in patients with an open bite, thus presenting the highest incidence compared to the

other groups of malocclusions; Deep bite patients showed a prevalence of hyperopia and strabismus two times bigger than control, showing alterations in saccadic movements and a fusional amplitude below the normal range. On the other hand, open bite patients showed the astigmatism prevalence four times bigger than control, showing also a low fusional amplitude and difficulty in the abilities of saccade movements. The value of this research is given by having investigated an aspect of the relationship between visual problems and malocclusion so far still little known. The results encourage a deepening of the investigations, to improve the approach to the prevention and treatment of patients in developmental age. This point of view is shared by Silvestrini et al. [29,30] that evaluated the dominant eye and the presence of vertical malocclusions. Most subjects had a right dominant eye. Subjects with an open bite showed a slightly different distribution in eye dominance, with a smaller difference between right or left preferences. Patients with a deep bite were similar to the control. Hence, it is necessary to create an investigation design constructed to evaluate the correlation of vertical malocclusions and ocular disorders.

Analyzing our sample, in patients with functional asymmetries we found a greater incidence of refractive vices (67%), of fusional vergence (52%) and an alteration of the saccades (56%); in patients with flawed habits, refractive defects occur at a rate of 61%, the amplitude was poor with 52%; while in patients with misalignment/crowding, refractive vices occur with 61%, the amplitude fused poorly with 57% and the alteration of the saccades with 57%.

A major limitation of studies of the causes of malocclusion is the multiplicity of its clinical manifestations and the multifactor character of the causes. For this reason, a study that observes more clinical and functional aspects that can interact with the craniofacial development cannot lead to evident results. However, there are many interesting aspects in this work that suggest continuing to investigate the relationship between vision problems and jaw development.

In particular, this research has the limitation of having separately considered myopia, hyperopia and astigmatism. Some children in the sample analyzed had astigmatism at the same time as myopia or hyperopia. However, in these aspects it was possible to compare with literature data. Instead, as regards the defects of ocular motility, this work provides results that have little precedent in the scientific literature.

5. Conclusions

Based on our results, it seems that exist a correlation between sagittal, transversal and vertical malocclusions with ocular disorders (myopia, hyperopia, astigmatism and ocular motility defects). For this reason, it would be advisable that visual exams should be added to the evaluation protocols used to analyze the stomatognathic system, since there is an interrelationship among malocclusions, visual problems and body posture. It has been shown that body compensation is present in a great prevalence when a malocclusion or visual defect is present. It is necessary to establish very well structured protocols of investigation to check the cause–effect relation and to establish preventive approaches when dealing with pediatric population.

Appendix A. NSUCO TEST

The NSUCO oculomotor test score implies giving precise values to the observations made by the clinician.

The clinician will score the score for both pursuits and saccades based on four factors: skill, precision, head movement and body movement. There are two types of aspects to be evaluated: the

qualitative aspect (based on the qualitative judgment of clinical performance) and the quantitative aspect (requires the clinician to count the number of times he observes a particular type of behavior).

- There are five qualitative aspects to be evaluated and include:

  1. movement of the head in the tracking movements;
  2. movement of the head in the saccades;
  3. movement of the body in the tracking movements;
  4. body movement in the saccades;
  5. accuracy of the saccade (amount above and below).

- There are three quantitative aspects to be evaluated and include:

  1. tracking skills (the number of rotations made clockwise and counterclockwise);
  2. saccadic ability (the number of round trips);
  3. accuracy of the activities (the number of losses or referrals).

Appendix B. Method Error for Evaluation of Malocclusions

The ROMA index was evaluated by operators who have previously undergone a one-month training period following the instructions in a specific manual, in order to apply the index with the same standard of judgment and to minimize errors.

To assess intraoperator reproducibility, the intraoperator error was calculated by repeating the examination for 20 children one month after.

A second operator independently collected a third table index for each of the 20 children to assess the interoperator error.

The Kappa values were between 0.643 and 1.00 for the intraoperator agreement ($0.00 < p < 0.002$) and between 0.773 and 1.00 for the agreement between operators ($p = 0 < 0.001$).

Table A1. ROMA index values.

GRADE 5		
Systemic problems		
	Malformation syndromes	5a
	Congenital malformations	5b
GRADE 4		
Systemic problems		
	Postural or orthopaedic problems	4c
	Medic or auxological problems	4d
	Genetic problems of the jaws	4e
Craniofacial problems		
	Facial or mandibular asymmetries	4f
	TMJ dysfunctions	4g
	Sequelae of trauma or surgery of the cranio-facial district	4j
	OVJ < 0 mm (maxillary hypodevelopment or mandibular hyperdevelopment)	4k
	OVJ > 6 mm (maxillary hyperdevelopment or mandibular hypodevelopment)	4h
	Mandibular hypo- or hyperdivergence	4i
Dental problems		
	Scissor bite	4m
	Anterior or posterior crossbite >2 mm	4n
	Displacement < 4 mm	4o
	Open bite > 4 mm	4p
	Hypodentia of permanent teeth	4q

Table A1. *Cont.*

GRADE 3		
Craniofacial problems		
	OVJ > 0 mm (maxillary hypodevelopment or mandibular hyperdevelopment)	3k
	3 mm < OVJ > 6 mm (maxillary hyperdevelopment or mandibular hypodevelopment)	3h
Dental problems		
	Caries and early loss of deciduous teeth	3l
	Anterior or posterior crossbite >1 mm	3n
	Displacement >2 mm	3o
	Open bite > 2 mm	3p
	Overbite > 5mm	3r
GRADE 2		
Craniofacial problems		
	0 mm < OVJ > 3 mm (maxillary hyperdevelopment or mandibular hypodevelopment)	2h
Dental problems		
	Anterior or posterior crossbite <1 mm	2n
	Displacement >1 mm	2o
	Open bite > 1 mm	2p
	Anomalies of the tooth eruption sequence	2s
	Poor oral hygiene	2t
	Normal mesial or distal occlusion (up to a cuspid)	2u
Functional problems		
	Functional asymmetries	2v
	Bad habits	2w
	Mouth breathing	2x
GRADE 1		
None of the problems listed above		N

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