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Longitudinal evaluation of sEMG of masticatory muscles and kinematics of mandible changes in children treated for unilateral cross-bite

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ABSTRACT

The aim of this study was to evaluate masticatory muscle activity and kinematics of mandible changes in children with unilateral posterior cross-bite (UPXB) after orthodontic treatment, and one year after retention. Twenty-five children with UPXB and functional mandibular shift were evaluated before treatment (mean age 12.5 years), after treatment (mean age 14.9 years), and one year after retention (mean age 16.8 years). The same data were collected in a control group of thirty age-matched normocclusive children. Simultaneous bilateral surface electromyographic (sEMG) activity from anterior temporalis (AT), posterior temporalis (PT), masseter (MA), and supra-hyoid (SH) muscle areas were evaluated at rest, during swallowing, mastication and clenching. Kinematic records of rest position, mandibular lateral shift, swallowing and mastication were analyzed. Results showed a lateral shift of the mandible present at rest. During swallowing, sEMG activity of SH predominated before and post-treatment and retention. High frequency of immature swallowing was maintained post-treatment and retention. During mastication, MA activity increased significantly and its asymmetry was corrected post-treatment. During clenching, cross-bite side AT and MA activity increased significantly posttreatment and remained stable after retention, and MA/AT ratio reversed. These findings reinforce the advantages of treating children with UPXB and functional shift as early as possible.

1. Introduction

Posterior lingual cross-bite is a transversal malocclusion that is prevalent among different populations, ranging from 7% to 23% in primary and mixed dentition (Kutin and Hawes, 1969; Thilander and Myrberg, 1973; Egermark-Eriksson et al., 1990; Kurol and Berglund, 1992). The condition appears very early during development of the dentition and in many cases does not present a spontaneous correction (Heikinheimo, 1978; Egermark-Eriksson, 1982). Unilateral posterior cross-bite (UPXB) is the most frequent presentation, usually associated with a functional lateral shift of the mandible toward the cross-bite side which causes midline deviation (Thilander et al., 1984; Kurol and Berglund, 1992). UPXB accompanied by a mandibular shift is commonly associated with certain functional deficiencies, such as asymmetrical activity in the masticatory muscles (Troelstrup and Moller, 1970; Ingervall and Thilander, 1975; Ferrario et al., 1999; Alarcon et al., 2000; Kecik et al., 2007), irregular masticatory patterns and alteration in masticatory cycle morphology (Throckmorton et al., 2001; Rilo et al., 2007), and increased prevalence of immature swallowing (Melsen et al., 1987; Martin et al., 2000).

Early treatment of UPXB is often advised to normalize occlusion and avoid future possible side-effects (Lindner, 1989; O'Byrn et al., 1995; Hesse et al., 1997; Sonnesen et al., 2001; Thilander and Lennartsson, 2002; Kecik et al., 2007). Rapid or slow maxillary expansion (ME) are common treatment modalities when the problem is located in the maxillary arch (Lindner et al., 1986; de Boer and Steenks, 1997; Hesse et al., 1997; Erdinc et al., 1999). Studies have evaluated surface electromyographic (sEMG) masticatory muscle activity after rapid ME in children with posterior cross-bite; however, their samples included both unilateral and bilateral posterior cross-bite (Arat et al., 2008; De Rossi et al., 2009), which present different neuromuscular features. Kecik et al. (2007) found that ME treatment of functional posterior cross-bite eliminated asymmetric morphology and position of the mandible and condyles, and improved activity of unbalanced masticatory muscles in children with UPXB.

Prospective longitudinal studies in children with UPXB evaluating changes in the stomatognathic system functions after

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orthodontic treatment and after a retention period are scarce. The aim of this longitudinal study was to evaluate sEMG masticatory muscle activity and kinematics of mandible changes in mandibular rest position, mandibular lateral shift, swallowing, mastication and maximal voluntary clenching (MVC) in children with UPXB after orthodontic treatment, and one year after retention.

2. Methods

2.1. Patients

Twenty-five children (10 boys, 15 girls), aged 10 to14 years-old at the beginning of the study, diagnosed with UPXB and functional mandibular lateral shift were recruited from referrals to the Pediatric Clinic at the School of Dentistry where the study took place. Posterior cross-bite was diagnosed by the visibility of at least one posterior tooth in full cross-bite, i.e., the buccal cusp of the upper tooth occluded lingually to the buccal cusp of the corresponding lower tooth.

Inclusion criteria were: Skeletal Class I (based on ANB angle, convexity, and Wits appraisal), mesofacial growth pattern (according to Fränkfort horizontal-to-mandibular plane angle on lateral cephalograms), and Caucasian origin. Exclusion criteria were presence of skeletal asymmetries (measured on frontal and Hirtz radiographs), craniofacial anomalies, temporomandibular joint dysfunction, history of neuromuscular disease or disease affecting neuromuscular performance, or previous or current orthodontic treatment.

Thirty age-matched children with normal occlusion (15 boys, 15 girls) were previously recruited at the same clinic to serve as a control group.

Patients were evaluated before orthodontic treatment (T0, mean age 12.5 years), immediately after treatment (T1, mean age 14.9 years), and one year after retention (T2, mean age 16.8 years). In the control group, data were collected at 1 time point (T0, mean age 12.5 years).

All patients' parents were informed on the characteristics of the study and agreed to participate by signing an EC-approved informed consent.

2.2. Orthodontic treatment

Orthodontic therapy consisted of symmetrical maxillary arch expansion with the Quad-helix (QH) appliance, which was made of 0.9 mm stainless steel wire and was activated once every 6–8 weeks during active treatment until cross-bite correction was achieved. The device was left intra-orally (without activation) for 4 months of retention. Thereafter, orthodontic treatment was continued with fixed appliances (0.018-inch-slot conventionally ligated Hilgers' edgewise bracket system; Ormco, Glendora, CA). Total active treatment length ranged from 2 to 2.5 years, followed by retention for 6 months with a removable circumferential Hawley-type retainer.

2.3. Electromyography measurements

The study was performed using an EM2® electromyograph (K6-I Diagnostic System®, Myotronics-Noromed, Kent, WA), with eight channels and a frequency bandwidth response of 45–430 Hz per channel that allows four pairs of muscles to be simultaneously tested. Disposable silver/silver chloride bipolar surface electrodes (Duo-Trode, Myotronics-Noromed, Kent, WA) were positioned (inter-electrode distance, 21 ± 1 mm) on muscle bellies parallel to muscle fibers according to a previously described protocol (Alarcon et al., 2009). Simultaneous bilateral surface electromyographic (sEMG) activity of the anterior temporalis (AT), posterior temporalis (PT), masseter (MA) and supra-hyoid (SH) areas was recorded at mandibular rest position, during swallowing, and during mastication. sEMG activity from bilateral AT and MA was obtained during MVC in maximal intercuspation. The asymmetry index (Naeije et al., 1989) was calculated for each muscle at rest and MVC, to quantify the degree of asymmetry between sides. MA/AT ratio during MVC was also recorded.

First, sEMG activity was recorded at rest; patients were requested to refrain from swallowing during the recording phase. Three consecutive 15-s recordings were made at 2-min intervals; the mean value was considered to be the resting sEMG activity (μV). sEMG activity during MVC was recorded with subjects encouraged to clench as hard as possible in maximal intercuspation. Three 3-s MVC trials were recorded at 2-min intervals. The highest sEMG activity (peak activity) measured was considered the MVC sEMG activity (μV). For swallowing, sEMG was registered as follows: subjects were instructed to take a mouthful of water and hold their jaws at rest position. They were then instructed to swallow the water and, after swallowing, to hold their jaws at rest position again. The peak activity (maximum amplitude, μV) was measured, and a 1-min rest period was allowed between each swallow. Lastly, sEMG was registered during mastication. The operator asked the subjects to eat chips without giving further instructions. Mean sEMG activity (μV) of the last 10 s of mastication was recorded.

During the experiment, subjects were seated in an upright position with the Fränkfurt plane parallel to the floor. Trial tests were permitted before the definitive recording. Irregular or spurious tracings were excluded for all tasks. To assess the reproducibility of sEMG data, 5 subjects underwent 4 trials over 4 days following a tested experimental protocol (Alarcon et al., 2009).

2.4. Kinematic measurements

Mandibular movements and position were recorded using a Kinesiograph computer system (K6-I Diagnostic System®, Myotronics-Noromed, Kent, WA), according to previously described protocols (Martin et al., 2000; Alarcon et al., 2009):

2.4.1. Mandibular shift evaluation

Functional mandibular lateral shift was defined as the difference (mm) between lateral shift of the mandible from maximum opening to maximal intercuspation. Negative values indicate lateral shift of the mandible toward the cross-bite side. We did not consider lateral shift as the difference between rest position and maximal intercuspation because functional mandibular lateral shift associated with unilateral posterior cross-bite may persist at rest position (Martin et al., 2000).

2.4.2. Rest position

To obtain the mandibular rest position, without occlusal contact, the patient was asked to moisten his/her lips, swallow saliva, breathe deeply, and relax his/her jaw with eyes closed. After recording in this position, the patient was asked to close to maximum intercuspation, and the vertical (freeway space), anteroposterior, and lateral displacements as the mandible moved upward from the rest position to maximum intercuspation were recorded (mm).

2.4.3. Swallowing

The swallowing mandibular movement was recorded during the intake of water. The distance the trace traveled from the endpoint of deglutition to maximum intercuspation represents the amount of space between the teeth (vertical space, mm).

2.4.4. Mastication

Mandibular movements were registered during the mastication of chips. The following variables were studied: XB and NON-XB side maximum opening, XB and NON-XB side maximum lateral displacement, and maximum mandibular retrusion during the cycle (mm). A preference for the XB or NON-XB side was determined after considering chewing strokes in the frontal plane using the preference indices (Wilding and Lewin, 1991).

As described in a previous study (Martin et al., 2000), reproducibility of the kinesiographic records was tested by comparing the results of 2 consecutive measurements of 10 randomly selected subjects.

2.5. Statistical analysis

SPSS 11.0 software (SPSS Inc, Chicago, IL) was used for statistical analysis. After establishing normality by the Shapiro–Wilks test, data were compared at T0 vs. T1 vs. T2 and between XB and NON-XB side muscle areas using a two-way repeated measures ANOVA followed by the Tukey–Kramer multiple-comparison test. One way repeated measures ANOVA (and the same post hoc test) was used to assess changes along time for those variables not affected by the "side" factor, such as the asymmetry indices. Conchran's Q test was used for categorical variables under the same scenario. Student t-test was used to compare normocclusive and crossbite children and the Fisher's exact test was applied to com-

Table 1
Comparisons of sEMG activity (μV) at rest position[a] and during swallowing[b], mastication[a] and clenching[b] between the control and cross-bite groups at the beginning of the study (T0). (Student t-test).

MUSCLE	Control		Cross-bite		Mean diff.	95% C.I.	*p*
	Mean	SD	Mean	SD			
Rest position							
XB anterior temporalis area	3.23	1.68	3.27	2.70	−0.04	−1.29 to 1.21	NS
NON-XB anterior temporalis area	1.97	0.99	2.27	1.43	−0.3	−1.08 to 0.48	NS
XB posterior temporalis area	3.87	2.36	3.27	2.77	0.6	−1.07 to 2.27	NS
NON-XB posterior temporalis area	4.03	3.29	4.46	2.81	−0.43	−2.25 to 1.39	NS
XB masseter area	2.67	2.26	1.66	1.24	1.01	−0.01 to 2.03	NS
NON-XB masseter area	3.20	4.11	1.52	1.01	1.68	−0.01 to 3.37	NS
XB supra-hyoid area	2.37	1.19	2.17	1.34	0.2	−0.54 to 0.94	NS
NON-XB supra-hyoid area	2.13	1.41	3.48	2.01	−1.35	−2.34 to −0.36	**
Anterior temporalis area AI (%)	5.75	12.49	8.43	28.94	−2.68	−18.96 to 13.6	NS
Posterior temporalis area AI (%)	2.04	36.53	−9.37	42.39	11.41	−14.17 to 36.99	NS
Masseter area AI (%)	−6.35	26.92	3.15	20.60	−9.50	−23.64 to 4.64	NS
Supra-hyoid area AI (%)	0.50	29.05	−13.57	38.78	14.07	−5.04 to 33.18	NS
Swallowing							
XB anterior temporalis area	58.14	56.10	61.18	60.64	−3.04	−40.0 to 33.92	NS
NON-XB anterior temporalis area	43.29	46.27	93.46	71.80	−50.17	−85.29 to −15.05	**
XB posterior temporalis area	43.21	23.26	61.56	51.00	−18.35	−51.06 to 14.36	NS
NON-XB posterior temporalis area	55.89	49.11	81.62	71.53	−25.73	−72.66 to 21.2	NS
XB masseter area	54.37	28.25	53.68	40.50	0.69	−23.53 to 24.91	NS
NON-XB masseter area	65.53	51.82	46.94	28.60	18.59	−17.93 to 55.11	NS
XB supra-hyoid area	92.31	35.74	137.93	89.79	−45.62	−88.51 to −2.73	*
NON-XB supra-hyoid area	103.52	64.65	128.58	60.88	−25.06	−67.79 to 17.67	NS
Mastication							
XB anterior temporalis area	40.90	18.33	44.81	19.38	−3.91	−16.79 to 8.97	NS
NON-XB anterior temporalis area	38.87	18.48	50.38	20.22	−11.51	−25.63 to 2.61	NS
XB posterior temporalis area	22.90	7.90	21.47	14.73	1.43	−7.69 to 10.55	NS
NON-XB posterior temporalis area	22.70	11.26	24.98	12.23	−2.28	−11.10 to 6.54	NS
XB masseter area	47.03	20.82	35.72	19.48	11.31	−2.45 to 25.07	NS
NON-XB masseter area	43.93	18.17	43.54	17.04	0.39	−11.82 to 12.60	NS
XB supra-hyoid area	26.40	10.78	30.89	16.81	−4.49	−12.8 to 3.82	NS
NON-XB supra-hyoid area	27.93	11.82	30.19	12.94	−2.26	−9.73 to 5.21	NS
Clenching							
XB anterior temporalis area	247.30	54.99	245.36	63.36	1.94	−38.49 to 42.37	NS
NON-XB anterior temporalis area	249.98	58.09	270.98	62.33	−21.0	−63.88 to 21.88	NS
XB masseter area	254.98	42.96	202.90	92.17	52.08	3.65 to 100.5	*
NON-XB masseter area	258.23	42.66	224.62	84.83	33.61	−10.37 to 77.59	NS
Anterior Temporalis area AI (%)	−4.29	18.35	−5.02	15.93	0.73	−9.63 to 11.09	NS
Masseter area AI (%)	1.12	23.70	−5.42	20.00	6.54	−6.82 to 19.9	NS
XB MA/AT areas ratio	1.1	0.67	0.84	0.34	0.26	−0.04 to 0.56	NS
NON-XB MA/AT areas ratio	0.99	0.32	0.86	0.33	0.13	−0.09 to 0.35	NS

AI: Asymmetry index.
XB: Cross-Bite (Right side in Control group); NON-XB: Non cross-bite (Left side in Control group).
MA: Masseter. AT: Anterior temporalis.
[a] Mean sEMG activity.
[b] Peak sEMG activity.
* $p < 0.05$.
** $p < 0.01$.

pare categorical variables between these two groups of subjects. The ANOVA for repeated measures test was also used to test EMG measurement reproducibility. Kinesiographic data reproducibility was tested using the paired t-test. Significance was set at the 5% level ($p \leqslant 05$).

3. Results

Reproducibility of EMG recordings was assessed from repeated measurements (4 trials) over different days obtained from different subjects. ANOVA results showed no systematic differences ($p > 0.05$). A paired Student's t-test found no systematic differences between the first and second data collection sessions ($p > 0.05$) of kinesiographic records.

Table 1 shows comparisons of sEMG activity between control and cross-bite groups at the beginning of the study (T0). During swallowing, NON-XB AT and XB SH showed significantly higher activity in the cross-bite group (93.46 ± 71.80 and 137.93 ± 89.79 μV) than in controls (43.29 ± 46.27 and 92.31 ± 35.74 μV). During clenching, XB MA showed lower activity in the cross-bite group (mean difference 52.08 μV, $p < 0.05$).

Comparisons between the three periods of the study in the cross-bite group are shown in Tables 2 and 3. Significant time-changes were found for sEMG muscle areas activity at rest position, mastication and clenching. MA/AT ratios during MVC also changed significantly with time, while no differences were found for sEMG values during swallowing and all asymmetry indices.

Post-hoc comparisons (Table 4) showed a significant reduction in the resting sEMG activity of XB AT, XB MA and NON-XB SH areas after treatment.

During mastication, XB PT, NON-XB PT, and XB MA areas showed significantly higher sEMG values after treatment and retention, indicating that the increased activity achieved after treatment remained stable. XB AT and NON-XB MA areas sEMG activities increased only after the retention period (T2-T0). Finally, during MVC, XB AT, XB MA, and NON-XB MA activities increased significantly after treatment, and continued to increase one year after retention. XB MA/AT ratio increased significantly ($p < 0.05$) one year after retention (T2-T1), from 0.93 (AT predominance) to 1.04. NON-XB MA/AT ratio also increased one year after retention ($p < 0.01$), from 1.02 to 1.15 (MA predominance).

When comparing sEMG activity differences between sides in the cross-bite group, only the MA muscle areas showed significant differences during mastication at T0: NON-XB MA showed higher activity than XB MA ($p < 0.05$). No differences were found between sides either after treatment or one year after retention. In the control group no differences were found between sides.

Table 5 presents kinematic data of mandibular lateral shift, rest position, swallowing and mastication, and comparisons between control and cross-bite groups at T0. Initial mandibular lateral shift and lateral displacement at rest were higher in the cross-bite group than in controls ($p < 0.001$). In cross-bite children immature

Table 3
Comparisons of mean values of Asymmetry Indices (%) at rest position (mean sEMG activity) and during clenching (peak sEMG activity) at T0, T1 and T2. (One-way ANOVA for repeated measurements) in the cross-bite group.

MUSCLE	T0		T1		T2		ANOVA
	Mean	SD	Mean	SD	Mean	SD	*p* Value
Rest position							
AT area AI (%)	8.43	28.94	2.00	31.56	−5.67	24.15	0.220
PT area AI (%)	−9.37	42.39	7.64	39.78	−0.13	31.63	0.295
MA area AI (%)	3.15	20.60	−2.23	14.98	4.34	19.99	0.421
SH area AI (%)	−13.57	38.78	1.36	16.19	16.51	59.47	0.057
Clenching							
AT area AI (%)	−5.02	15.93	0.34	12.56	2.45	13.82	0.165
MA area AI (%)	−5.42	20.00	−2.02	16.79	−1.76	10.25	0.674

AT: Anterior temporalis; PT: Posterior temporalis; MA: Masseter; SH: Supra-hyoid; AI: Asymmetry index.

Table 2
Comparisons of mean values of sEMG activity (μV) at rest position[a], during swallowing[b], mastication[a] and clenching[b] at T0, T1 and T2 (Two-way ANOVA for repeated measurements) in the cross-bite group.

MUSCLE	T0				T1				T2				ANOVA		
	XB		NON-XB		XB		NON-XB		XB		NON-XB		*p* value		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Time	Side	Interaction
Rest position															
AT area	3.27	2.70	2.27	1.43	1.66	1.13	1.61	1.19	1.48	0.82	1.67	1.10	<0.001	0.251	0.123
PT area	3.27	2.77	4.46	2.81	3.38	2.60	2.77	2.09	4.07	2.29	4.10	2.03	0.099	0.612	0.181
MA area	1.66	1.24	1.52	1.01	0.93	0.54	1.00	0.65	1.10	0.67	1.04	0.68	<0.001	0.751	0.818
SH area	2.17	1.34	3.48	2.01	1.64	0.83	1.68	1.02	1.91	1.18	1.66	1.06	<0.001	0.085	0.007
Swallowing															
AT area	61.18	60.64	93.46	71.80	53.56	54.21	58.48	40.85	58.13	53.80	61.64	41.10	0.122	0.129	0.342
PT area	61.56	51.00	81.62	71.53	92.31	70.06	98.19	93.65	57.82	33.70	73.21	54.25	0.058	0.196	0.858
MA area	53.68	40.50	46.94	28.60	64.20	43.26	60.06	78.16	62.15	41.27	68.09	48.02	0.283	0.838	0.793
SH area	137.93	89.79	128.58	60.88	121.34	66.52	125.34	71.89	112.90	82.35	109.00	76.76	0.335	0.802	0.906
Mastication															
AT area	44.81	19.38	50.38	20.22	59.89	21.98	58.91	26.43	62.38	24.16	61.65	28.44	0.006	0.740	0.736
PT area	21.47	14.73	24.98	12.23	36.48	18.48	36.24	17.06	37.07	17.69	39.74	18.62	<0.001	0.467	0.840
MA area	35.72	19.48	43.54	17.04	55.69	23.26	55.71	21.18	57.67	20.73	58.88	22.78	<0.001	0.049	0.035
SH area	30.89	16.81	30.19	12.94	25.41	10.17	25.00	9.45	33.31	49.46	31.87	48.48	0.451	0.863	0.996
Clenching															
AT area	245.36	63.36	270.98	62.33	317.79	69.27	316.32	77.87	327.93	87.41	314.45	103.40	<0.001	0.782	0.446
MA area	202.90	92.17	224.62	84.83	295.10	84.66	304.20	73.21	328.81	86.91	333.64	80.58	<0.001	0.387	0.872
MA/AT areas ratio	0.84	0.34	0.86	0.33	0.93	0.19	1.02	0.37	1.04	0.21	1.15	0.34	<0.001	0.143	0.741

XB: Cross-Bite side; NON-XB: Non cross-bite side; AT: Anterior temporalis; PT: Posterior temporalis; MA: Masseter; SH: Supra-hyoid.
[a] Mean sEMG activity.
[b] Peak sEMG activity.

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Table 4
Mean differences (T1 vs. T0; T2 vs. T1, T2 vs. T0) of sEMG activity (μV) at rest position[a] and during swallowing[b], mastication[a] and clenching[b]. (Tukey post-tests performed after two-way Anova for repeated measurements shown in table 2) in the cross-bite group.

MUSCLE	T1 – T0			T2 – T1			T2 – T0		
	Mean	SD	*p*	Mean	SD	*p*	Mean	SD	*p*
Rest position									
XB anterior temporalis area	−1.61	5.01	***	−0.18	1.13	NS	−1.79	5.28	***
XB masseter area	−0.73	1.28	**	0.17	0.68	NS	−0.56	1.28	*
NON-XB supra-hyoid area	−1.80	4.92	***	−0.02	1.34	NS	−1.82	5.21	***
Mastication									
XB anterior temporalis area	15.08	20.38	NS	2.49	22.19	NS	17.57	27.09	*
XB posterior temporalis area	15.01	18.57	**	0.59	19.47	NS	15.60	19.46	**
NON-XB posterior temporalis area	11.26	20.82	*	3.50	17.73	NS	14.76	20.98	**
XB masseter area	19.97	28.70	**	1.98	25.62	NS	21.95	26.06	***
NON-XB masseter area	12.17	26.69	NS	3.17	28.99	NS	15.34	31.52	*
Clenching									
XB anterior temporalis area	72.43	84.39	**	10.14	27.45	NS	82.57	86.92	***
XB masseter area	92.20	94.39	***	31.67	37.38	NS	125.90	98.14	***
NON-XB masseter area	79.58	95.74	**	24.02	25.79	NS	109.00	95.95	***
XB MA/AT areas ratio	0.09	0.33	NS	0.11	0.25	*	0.20	0.25	NS
NON-XB MA/AT areas ratio	0.16	0.37	NS	0.13	0.46	**	0.29	0.46	NS

XB: Cross-Bite. NON-XB: Non cross-bite.
MA: Masseter. AT: Anterior temporalis.
[a] Mean sEMG activity.
[b] Peak sEMG activity.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 5
Comparisons of kinematic measurements (mm) of mandibular shift, rest position, swallowing and mastication between the control and cross-bite groups at the beginning of the study (T0). (Student-t test except for swallowing patterns and differences between masticatory preference indices, where Fisher's exact test was used).

PARAMETER	Control		Cross-bite		Mean diff.	95% C.I.	*p*
	Mean	SD	Mean	SD			
Mandibular lateral shift	1.06	2.60	−1.27	1.09	2.33	1.2 to 3.47	***
Rest position							
Vertical freeway space	2.63	1.38	2.86	1.44	−0.23	−1.07 to 0.61	NS
Antero-posterior displacement	0.70	0.84	0.92	0.52	−0.11	−1.13 to 0.91	NS
Lateral displacement	0.13	0.43	−0.22	0.06	0.35	0.18 to 0.52	***
Swallowing							
Adult swallowing (%)	73.33		40.00		23.33		**
Immature swallowing (%)	26.67		60.00		−33.33		**
Vertical space (mm)	0.54	1.11	2.56	1.42	−2.02	−2.75 to −1.29	***
Mastication							
Maximum opening	17.87	4.48	14.46	3.23	3.41	0.99 to 5.83	**
Maximum lateral displacement	5.97	2.02	3.91	2.29	2.06	0.68 to 3.44	**
Maximum amplitude	9.10	3.02	9.14	2.31	−0.04	−1.65 to 1.57	NS
Maximum retrusion	6.50	2.86	6.66	2.28	−0.16	−2.03 to 1.71	NS
XB preference (% of cycles)	38.73	39.35	40.76	25.16	−2.03		NS
NON-XB preference (% of cycles)	61.27	34.14	59.24	25.17	2.03		NS

XB: Cross-Bite side (Right side in Control group); NON-XB: Non cross-bite side (Left side in Control group).
** $p < 0.01$.
*** $p < 0.001$.

swallowing was more frequent than in controls (60% vs. 26.67%) and the vertical space during swallowing was higher (2.56 ± 1.42 vs. 0.54 ± 1.11). During mastication, maximum opening and maximum lateral displacement were lower in the cross-bite group than in the controls ($p < 0.01$).

Comparisons between the three periods of the study in the cross-bite group are shown in Table 6. Significant differences were found for the following variables: mandibular lateral shift, vertical free way space and lateral displacement at rest position, vertical space during swallowing and maximum lateral displacement, maximum amplitude and maximum retrusion during mastication. Post-hoc comparisons are listed in Table 7. The initial lateral shift of the mandible toward the XB side improved significantly after treatment. At rest, vertical free space decreased significantly after treatment and one year after retention. The initial lateral displacement of the mandible from rest position to maximum intercuspation toward the XB side disappeared after treatment and remained stable one year after retention. No significant changes were found

Table 6
Comparisons of kinematic measurements (mm) of mandibular shift, rest position, swallowing and mastication, before treatment (T0), after treatment (T1) and one year after retention (T2) (One-way ANOVA for repeated measurements except for % of swallowing and XB and NON-XB side preferences, where Cochran's Q test was used) in the cross-bite group.

Parameter	T0		T1		T2		*p*
	Mean	SD	Mean	SD	Mean	SD	
Mandibular lateral shift	−1.27	1.09	−0.82	0.69	0.82	0.53	<0.001
Rest position							
Vertical freeway space	2.86	1.44	1.26	1.02	0.91	0.64	<0.001
Antero-posterior displacement	0.92	0.52	0.81	0.61	0.82	0.63	0.766
Lateral displacement	−0.22	0.06	0.02	0.02	0.03	0.02	<0.001
Swallowing							
Adult swallowing (%)	40.00		40.00		44.00		0.368
Immature swallowing (%)	60.00		60.00		56.00		0.368
Vertical space	2.56	1.42	1.46	0.76	1.29	0.79	<0.001
Mastication							
Maximum opening	14.46	3.23	15.90	3.15	16.12	4.78	0.251
Maximum lateral displacement	3.91	2.29	6.22	2.08	5.55	1.77	<0.001
Maximum amplitude	9.14	2.31	12.65	1.87	11.76	1.82	<0.001
Maximum retrusion	6.66	2.28	8.92	3.40	10.90	4.12	<0.001
XB preference (% of cycles)	40.76		51.06		48.11		0.097
NON-XB preference (% of cycles)	59.24		48.98		52.56		0.097

XB: Cross-Bite side; NON-XB: Non cross-bite side.

Table 7
Mean differences (T1 vs. T0; T2 vs. T1, T2 vs. T0) for kinematic measurements (mm) of mandibular shift, rest position, swallowing and mastication (Tukey post-tests performed after one-way Anova for repeated measurements shown in table 6) in the cross-bite group.

Parameter	T1 − T0			T2 − T1			T2 − T0		
	Mean diff.	SD	*p*	Mean diff.	SD	*p*	Mean diff.	SD	*p*
Mandibular lateral shift	0.45	0.40	NS	1.64	1.09	***	2.09	1.81	***
Rest position									
Vertical freeway space	−1.60	1.75	***	−0.35	1.12	NS	−1.95	1.55	***
Lateral displacement	0.24	0.02	***	0.01	0.01	NS	0.25	0.02	***
Swallowing									
Vertical space	−1.10	0.72	**	−0.17	0.12	NS	−1.27	1.03	***
Mastication									
Maximum lateral displacement	2.31	2.93	***	−0.67	2.14	NS	1.64	2.67	*
Maximum amplitude	3.51	2.73	***	−0.89	−0.36	NS	2.62	2.51	***
Maximum retrusion	2.26	3.41	NS	1.98	4.63	NS	4.24	3.90	***

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

in immature swallowing between T0, T1, and T2, although vertical space during swallowing decreased after treatment and continued to decrease one year after retention. During mastication, maximum lateral displacement and maximum amplitude increased significantly after treatment and remained stable one year after retention. Maximum retrusion also increased, but only from T0 to T2. No differences were found in preference indices at any time period.

4. Discussion

This study used sEMG of masticatory muscles and mandibular kinematics to evaluate longitudinal changes in mandibular rest position, mandibular lateral shift, swallowing, mastication and maximal voluntary clenching immediately after orthodontic treatment and one year after retention.

We acknowledge that one limitation of this study is the lack of a longitudinal control group with normal occlusion throughout all phases of the study; however, there are few, if any, published studies including normative values of sEMG masticatory muscles and mandibular kinetics in growing children. Additionally, the aim of this study was mainly to analyze muscular and kinematic longitudinal changes after orthodontic treatment and retention. We used a control normocclusive group to compare with the cross-bite group at the base line (T0), before the start of treatment, and a within-subject design in the cross-bite group to compare changes after treatment (T1) and retention (T2), and between sides, so that each subject served as his/her own control (Arat et al., 2008; De Rossi et al., 2009).

In addition to the use of QH to produce symmetrical maxillary arch expansion until UPXB correction, treatment was continued with preadjusted fixed appliances to achieve a stable occlusion, free of occlusal interference or problems that could affect sEMG activity or mandible kinematics (Riise and Sheikholeslam, 1982; Sheikholeslam and Riise, 1983; Riise and Sheikholeslam, 1984;

Bakke et al., 1992; Bakke and Moller, 1992; Baba et al., 1996; De Rossi et al., 2009). Also, patients were observed until one year after retention to control muscular function until treatment stabilization and maturation of the stomatognathic system.

4.1. Rest position

Before treatment, PT showed higher sEMG activity than other muscles in both cross-bite and control groups, reinforcing the important role of PT muscles in the stabilization and positioning of the mandible at rest (Ingervall and Thilander, 1975; Ahlgren, 1985; Jimenez, 1989).

sEMG activity of XB AT, XB MA and NON XB SH decreased significantly after treatment, reaching similar values as the corresponding contra-lateral muscles. This reduction remained stable one year after retention. In this sense, a more physiological muscular condition at rest was achieved after orthodontic treatment.

Vertical freeway space decreased significantly after treatment, from 2.86 ± 1.44 mm to 1.26 ± 1.02 mm, and continued to decline one year after the retention period. At the end of the study the mean freeway space was 0.91 ± 0.64 mm, similar to means reported for normocclusive young adults (Kang et al., 1991) and normocclusive mesofacial patients (Konchak et al., 1987). This reduction could be explained by changes due to growth and correction of the malocclusion.

No significant antero-posterior displacement of the mandible was shown after treatment and retention. Antero-posterior space was similar to values reported for normocclusive children (Martin et al., 2000) and young adults (Kang et al., 1991).

After treatment, a significant reduction was shown in the lateral displacement of the mandible at rest (0.24 ± 0.02 mm), which was maintained after the retention period, showing similar values to those found in the normocclusive control group. These results indicate that after orthodontic treatment and retention the slight shift of the mandible at rest was also corrected. Mandibular lateral shift improved, but not completely, and a slight lateral shift toward the XB side persisted after treatment. After retention, a small shift to the opposite side was found. These results can be interpreted as a consequence of the remodeling processes that take place at temporomandibular joints (Pirttiniemi et al., 1990). Final mandibular displacement was quite similar to that found in the nomocclusive control group at the beginning of the study. In the study by Kecik et al. (2007) lateral shift was corrected from 3.26 ± 2.53 mm to 0.49 ± 0.38 mm after treatment of functional posterior crossbite in mixed dentition.

4.2. Swallowing

A remarkable finding of the study was the high SH sEMG activity observed at all time points in the study in the cross-bite group. These results could be explained by the high frequency of immature swallowing shown by kinesiographic records. Immature swallowing is characterized by interposition of the tongue between the teeth and by higher activity of digastric muscles compared to masseter and anterior temporalis muscles (Stormer and Pancherz, 1999).

Before treatment, NON-XB AT sEMG activity was higher in the cross-bite group than in the control group, but after treatment this muscle decreased its activity, getting closer to the values found in controls at T0. In the cross-bite group, AT activity decreased while MA activity increased after treatment, reaching similar values or even slight predominance of MA muscles, as in control children (T0). These results were not significant but show a tendency to a normalization in the function of AT and MA muscles during swallowing.

After treatment and retention no significant differences were found in the percentage of patients with inmature and adult swallowing, reflecting that orthodontic treatment alone did not modify immature swallowing in children with UPXB, although vertical space was significantly reduced.

4.3. Mastication

Average sEMG activity of the last 10 s of the chewing cycle was recorded to evaluate muscular development during the global masticatory cycle, rather than specific phases. Subjects were simply asked to eat, and were not given further instructions in order to obtain spontaneous mastication. In other studies, subjects were asked to chew unilaterally (left and right; (Ferrario and Sforza, 1996; Ferrario et al., 1999) which could influence the mean sEMG activity during the masticatory cycle (Plesh et al., 1996).

sEMG activity of XB and NON-XB PT and XB MA muscle areas increased significantly after treatment and remained stable after retention, while XB AT and NON-XB MA muscle areas activity increased from T0 to T2. Therefore, the functional capacity of the masticatory muscles during mastication improved after orthodontic treatment of UPXB. In previous studies (Alarcon et al., 2000, 2009) it was hypothesized that the occlusal condition developed in response to UPXB could generate an inhibitory-protective reflex over masticatory muscles to avoid injury of the structures of the stomatognathic system that would disappear after stable occlusion was achieved. Other researchers found a correlation between occlusal stability and elevator muscle function, likely based on feedback mechanisms from periodontal pressoreceptors (Bakke et al., 1992).

The initial MA muscle areas asymmetry (NON-XB MA showed higher activity than XB MA) disappeared after treatment. Bilateral MA activity increased after treatment, but the XB MA activity increased more, thereby correcting the asymmetry. Changes found in the activity of masticatory muscles during mastication reinforce the benefits of treating the UPXB as early as possible.

Before treatment, we observed a significant restriction in the maximum opening and maximum lateral displacement of the mandible in the cross-bite group, compared to controls, as other researchers have reported (Saitoh et al., 2002). After treatment, maximum lateral displacement and maximum amplitude increased significantly and remained stable after retention. On the contrary, Throckmorton et al. (2001) reported that maximum lateral excursion did not change significantly after treatment.

Maximum retrusion increased significantly from 6.66 ± 2.28 mm at T0 to 10.90 ± 4.12 mm at T2. In the control subjects of Throckmorton et al. (2001), maximum retrusion increased after a similar period; therefore, the changes observed in our patients could be attributed to a combination of growth and orthodontic treatment.

There was no relationship between crossbite side and masticatory preference side at any point in the study, although mastication tended to be more symmetric (approximately 50% of the masticatory cycle per side) after treatment and retention. Some studies found no chewing side preference in children with UPXB (Pond et al., 1986; Martin et al., 2000); others found a preference for unilateral chewing (Michler et al., 1987; Egermark-Eriksson et al., 1990). According to previous studies, masticatory preference is determined by the number and stability of occlusal contacts (van der Bilt et al., 1994; Bourdiol and Mioche, 2000) that improve masticatory efficacy (Mioche et al., 1999). It could therefore be speculated that even in the presence of UPXB, patients can achieve adequate occlusal stability to avoid development of masticatory preference.

4.4. Clenching

The highest EMG peak value during MVC was used to better understand the functional capacity of jaw muscles (MM and AT). It was also used during swallowing for the same reason.

Before treatment, MA/AT ratio revealed a predominance of the AT over the MA in both XB (0.84) and NON-XB (0.86) sides in the cross-bite group, while in the control children the activity of both AT and MA was similar (MA/AT ratio values around 1). In normally developed young adults, MA activity was higher than AT activity (Miralles et al., 1991; Ferrario et al., 1993). After treatment, NON-XB side MA/AT ratio increased, balancing the activity of both muscles, while in the XB side MA/AT ratio also increased, but AT activity still predominated over MA activity. Nevertheless, after retention, the activity of both muscles was quite similar in the XB side (MA/AT ratio: 1.04), while in the NON-XB side MA activity slightly predominated over AT activity (MA/AT ratio: 1.15). Therefore, the activity of these muscles normalized after retention, approaching that observed in our control normocclusive group at T0 and in normocclusive young people from other studies.

XB MA activity was significantly lower in the cross-bite group than in controls at T0. Nevertheless, XB MA activity increased significantly after treatment and remained stable after retention, as others muscle areas (XB AT, and NON-XB MA). These changes can be attributed to both growth and development of the children and the orthodontic treatment. Treatment improved the occlusal conditions, increasing both occlusal contact quality and occlusal stability. Our results agree with those of studies that consider occlusal stability the most important factor for the development of elevator masticatory muscles (Gydikov et al., 1980; Jimenez, 1987; Bakke and Michler, 1991).

5. Conclusions

Longitudinal evaluation of sEMG of masticatory muscles and kinematics of mandible changes after treatment and retention in a group of children with UPXB led to the following conclusions:

- Lateral shift of the mandible was also present at rest position.
- During swallowing, sEMG activity of SH was predominant before and after treatment and retention, probably due to the high frequency of immature swallowing found among the patients, which was maintained after treatment and retention. Orthodontic treatment alone did not modify immature swallowing in children with UPXB.
- Orthodontic treatment improved the functional capacity of the masticatory muscles during mastication: sEMG activity of XB MA increased significantly after treatment and remained stable after retention; the initial asymmetry found in MA (XB MA showed less activity than NON-XB MA) was also corrected after treatment; and maximum lateral displacement of the mandible and maximum amplitude increased after treatment.
- During clenching, the activity of XB-AT and XB MA and NON-XB MA muscles areas increased significantly after treatment and remained stable after retention. The initial predominance of AT over MA activity (MA/AT ratio) reversed after retention, leading to normalization of the activity of these muscles.

Our findings reinforce the advantages of treating children with UPXB and functional mandibular lateral shift as early as possible. Longitudinal studies including a normooclusive-matched control group are needed to clarify which changes may be specifically attributed to the orthodontic treatment and retention.

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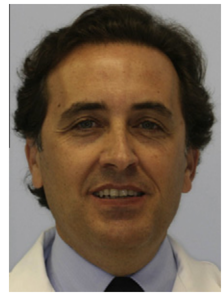

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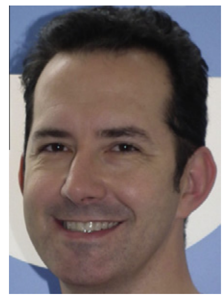

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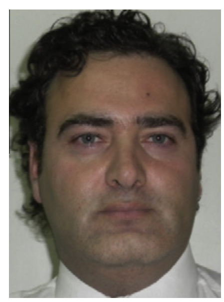

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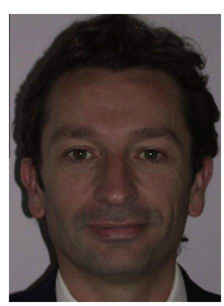

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