ORIGINAL ARTICLE

Evaluation of the treatment changes of functional posterior crossbite in the mixed dentition

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Introduction: Functional posterior crossbite (FPXB) malocclusion is frequently seen in the deciduous or mixed dentition. It is often accompanied by lateral mandibular shift and mandibular midline deviation because of the reduction in the width of the maxillary dental arch. The aims of this prospective study were to examine in detail the morphologic, skeletal, dental, and functional effects of FPXB, and the effects of maxillary expansion treatment with quad-helix appliance. **Methods:** The experimental group consisted of 35 FPXB patients (20 girls, 15 boys) having a mean age of 10.6 ± 1.4 years; the control group consisted of 31 normocclusive subjects (18 girls, 13 boys) with a mean age of 9.8 ± 1.6 years. Lateral, posteroanterior, and submentovertex cephalograms, transcranial temporomandibular joint radiographs, joint vibration analysis, and electromyographic recordings were obtained from every patient before and after maxillary expansion. Magnetic resonance images were taken before treatment for diagnostic purposes. These data were collected at 1 time point in the controls. **Results:** The pretreatment posteroanterior, submentovertex, and transcranial temporomandibular joint radiographs showed mandibular asymmetry relative to the cranial base and condylar malpositioning in the glenoid fossa. Joint vibration analysis findings showed different vibrations between the crossbite and noncrossbite sides, and imbalanced electromyographic findings in the experimental group. After treatment, the asymmetric morphology and position of the mandible and condyles were eliminated, and the stomatognathic system functions were normalized. **Conclusions:** Early orthodontic treatment of FPXB creates optimum conditions for normal growth of the craniofacial skeleton and normal function of the stomatognathic system. (Am J Orthod Dentofacial Orthop 2007;131:202-15)

Posterior crossbite is a relatively frequent malocclusion in deciduous and mixed dentititons, defined as a malocclusion in the canine and premolar regions, characterized by the buccal cusps of the maxillary teeth occluding lingually to the buccal cusps of the corresponding mandibular teeth,[1] with a prevalance between 7% and 23%.[1-13] Crossbite can involve 1 tooth or a group of teeth. It can have a skeletal or dentoalveolar origin, either unilateral or bilateral. When the intercuspal position of the mandibular dentition is forced laterally to the retruded contact position, this condition is described as a functional posterior crossbite (FPXB).[1] FPXB is generally accompanied by deviation of the mandibular arch midline to the crossibite side.[13-15] The most frequent cause of FPXB is the reduction in width of the maxillary dental arch. Such a reduction can be induced by finger sucking,[2,13,16,17] certain swallowing habits,[2] or obstruction of the upper airways caused by adenoid tissues or nasal allergies.[17-21]

Studies have shown that crossbite, especially when associated with a lateral shift, plays an important role in craniomandibular disorders.[3,13-15,22] Since posterior crossbite generally causes dual bite with a lateral mandibular shift, an asymmetrical condylar movement pattern can occur.[15,22] Changes in condylar movement might induce asymmetrical mandibular growth.[12,23,24] The diagnosis of FPXB is based on an asymmetric mandibular shift from centric relation to intercuspal position. Patients with FPXB have mandibles positioned asymmetrically or even morphologic asymmetry.[25] Children with functional crossbites have varying degrees of morphologic and positional asymmetries. Schmid et al[26] indicated that morphological asymmetry in growing children is the result of mandibular displacement consequent to occlusal alterations. Positional asymmetries might have immediate morphological

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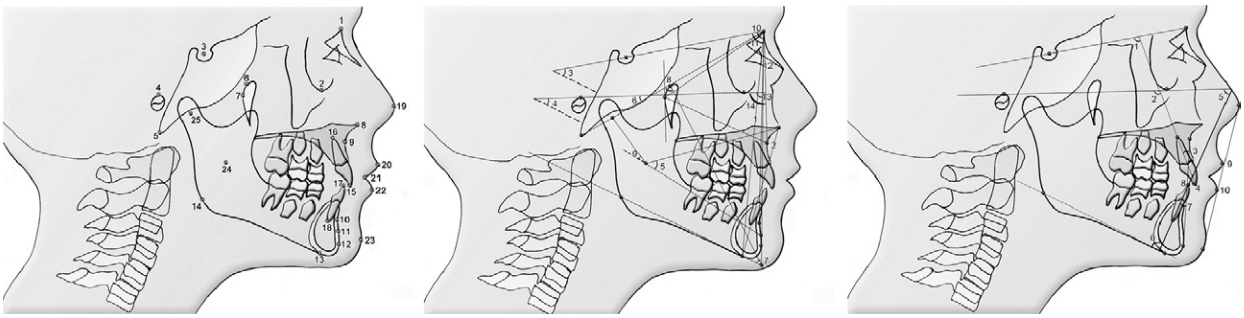

Fig 1. **A,** Hard- and soft-tissue landmarks used in lateral cephalometric radiographs: *1,* nasion (Na); *2,* orbitale (Or); *3,* sella (S); *4,* porion (Po); *5,* basion (Ba); *6,* pterygoid (Pt); *7,* pterygoid vertical (Ptv); *8,* anterior nasal spine (ANS); *9,* A-point (A); *10,* B-point (B); *11,* Pm point (Pm) [suprapogonion]; *12,* pogonion (Pog); *13,* menton (Me); *14,* gonion (Go); *15,* maxillary incisor incisal point (Ui); *16,* maxillary incisor root apex point (Ua); *17,* mandibular incisor incisal point (Li); *18,* mandibular incisor root apex point (La); *19,* prosthion (Prn); *20,* upper lip (UL); *21,* embrasure point; *22,* lower lip (LL); *23,* soft-tissue pogonion (Pog′); *24,* Xi point (Xi); 25, DC point (DC). **B,** Skeletal angular and linear measurements of lateral cephalograms: *1,* nasion-menton distance (Na-Me); *2,* ANS-menton distance (ANS-Me); *3,* GoGnSN angle (GoGnSN); *4,* FMA angle (FMA); *5,* lower facial height angle (ANS-Xi-Pm); *6,* cranial deflection angle (CD); *7,* facial taper angle (FT); *8,* facial axis angle (FA); *8,* mandibular arch angle (MA); *10,* SNA angle (SNA); *11,* SNB angle (SNB); *12,* ANB angle (ANB); *13,* facial depth angle (FD); *14,* maxillary depth angle (MD). **C,** Dental angular and linear measurements and soft-tissue measurements of lateral cephalograms: *1,* maxillary central incisor to SN plane angle (U1-SN); *2,* maxillary central incisor to FH plane angle (U1-FH); *3,* maxillary central incisor to APog line angle (U1-APog); *4,* maxillary central incisor to APog line distance (U1-APog); *5,* FMIA angle; *6,* IMPA angle; *7,* mandibular central incisor to APog line angle (L1-APog); *8,* mandibular central incisor to APog line distance (L1-APog); *9,* upper lip to esthetic plane (UL-E); *10,* lower lip to esthetic plane (LL-E).

consequences. Occlusal disturbances characteristic of FPXB are beleived to play a role in the etiology of temporomandibular joint (TMJ) disorders.[27,28] In children with FPXB, it was demonstrated that the condyles on the 2 sides are relatively malpositioned in their fossae.[15,22] The condyles on the crossbite side are positioned relatively more superiorly and posteriorly in the glenoid fossae than those on the noncrossbite side.[15,22] Asymmetric postural muscle activity was also reported in children with FPXB.[29-31] If the FPXB is left untreated, it can have deleterious effects on the development and function of the TMJ. Skeletal remodelling of the TMJs can occur over time so that the condyles become more symmetrically positioned in their fossae, and facial asymmetry and mandibular midline deviation toward the crossbite side might persist. Subsequent adaptation of the neuromusculature to the acquired mandibular position can cause asymmetric mandibular growth, facial disharmony, and severe skeletal crossbite in the permanent distortion.[24,32]

Because spontaneous correction is rare, early treatment has been advocated.[13,24,33-35] Maxillary expansion is the treatment choice for FPXB because it resolves the transverse maxillary deficiency and allows the mandible to regain a normal centric relation-intercuspal position relationship. Several devices are available for the correction of FPXB, such as rapid palatal expanders[22,36-38] quad-helix appliances,[34,37,39,40] slow maxillary expansion appliances such as nickel-titanium alloy devices,[41] Warch,[40] tandem loop,[42] and removable maxillary expansion appliances.[37,39,43]

The aims of this prospective study were to investigate the stomatognathic changes of patients with FPXB in the mixed dentition via radiographic methods, joint vibration analysis, and electromyography (EMG) recordings; to compare the changes before and after treatment; and to compare these findings with the records of the control group taken at 1 time point.

SUBJECTS AND METHODS

This prospective study was carried out with 2 groups of children in the mixed dentition stage: an experimental group with FPXB and a control group without malocclusion. The children in the FPXB group received detailed functional analyses including TMJ examination and chewing muscle palpation. The patients in the experimental group had unilateral posterior crossbites at maximum intercuspal position with a

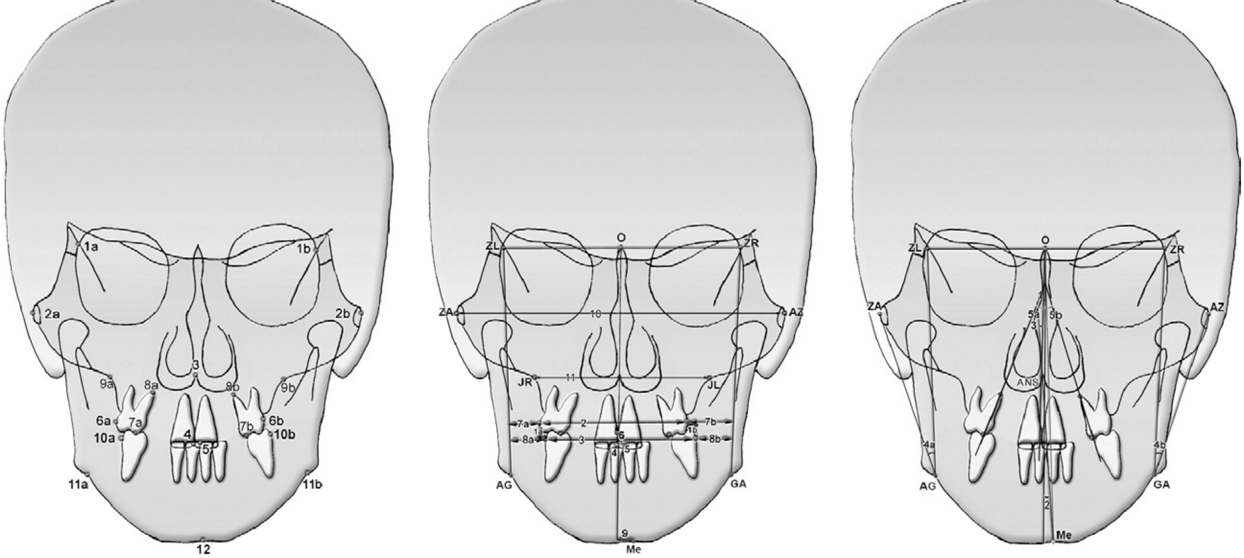

Fig 2. A, Landmarks used in posteroanterior cephalometric radiographs (*a,* right side; *b,* left side): *1,* ZR and ZL, intersection point of zygomaticofrontal suture with orbita; *2,* ZA and AZ, center of root of zygomatic arch; *3,* ANS, upper point of anterior nasal spine; *4,* U1, proximal incisal point between maxillary central incisors; *5,* L1, proximal incisal point between mandibular central incisors; *6*, U6, buccal contour crest of maxillary first molar; *7,* U6P, palatal cusp tip of maxillary first molar; *8,* U6A, palatal root apex of maxillary first molar; *9,* JL and JR, intersection point of tuber maxilla and zygomatic arch on jugular process; *10,* L6, buccal contour crest of first molars; *11,* AG and GA, lateral and inferior point of antegonial protuberentia; *12,* Me, menton. **B,** Linear measurements of posteroanterior cephalograms: *1,* molar relationship (MR); *2,* upper intermolar width (UIMW); *3,* lower intermolar width (LIMW); *4,* maxillary dental midline to midsagittal plane (U1-MSP); *5,* mandibular dental midline to midsagittal plane (L1-MSP); *6,* maxillary and mandibular dental midline distance (U1-L1); *7,* maxillary molar-facial plane distance (U6-FP); *8,* mandibular molar-facial plane distance (L6-FP); *9,* menton-midsagittal plane distance (Me-MSP); *10,* facial width (FW), distance between AZ and ZA points; *11,* maxillary base width: distance between JR and JL points. **C,** Angular measurements of posteroanterior cephalograms: *1,* transverse maxillary position angle (TMxA), angle between O-ANS line and midsagittal plane; *2,* transverse mandibular position angle (TMdA), angle between O-Me line and midsagittal plane; *3,* transverse jaw relationship (TJR), angle between O-ANS line and O-Me line; *4,* positional symmetry angle (PSA), angle between ZA-AG-ZR points on right side and ZL-GA-ZL points on left side; *5,* inclination angle of the maxillary first molar (U6 inc), angle between maxillary molar axis (line passing through palatal cusp tip and palatal root apex) and midsagittal plane.

midline shift through the crossbite side. The midline shift disappeared, and the maxillary and mandibular midlines coincided at mouth opening; indicating that the patients had FPXB. The FPXB group consisted of 35 patients (20 girls, 15 boys), and the control group consisted of 31 subjects (18 girls, 13 boys). The mean ages were 10.6 $\pm$ 1.4 years for the FPXB group and 9.8 $\pm$ 1.6 years for the control group. All children had Angle Class I skeletal relationships. The mode of treatment consisted of symmetrical maxillary arch expansion with the quad-helix appliance fabricated on each patient's diagnostic model. Success of treatment was defined as complete elimination of the FPXB.

The data were collected at 1 time point in the controls, and before treatment and 6 months after treatment (3 months of expansion and 3 months of retention) in the FPXB group. To exclude a craniomandibular disorder, a specific questionnaire was given, and anamnesis was taken. Clinical examination included measurement of range of mandibular movement, auscultation and palpation of the TMJs, and palpation of the masticatory and neck muscles. The exclusion criteria were genetic or congenital abnormalities, systemic diseases affecting growth and development negatively, and congenitally missing teeth.

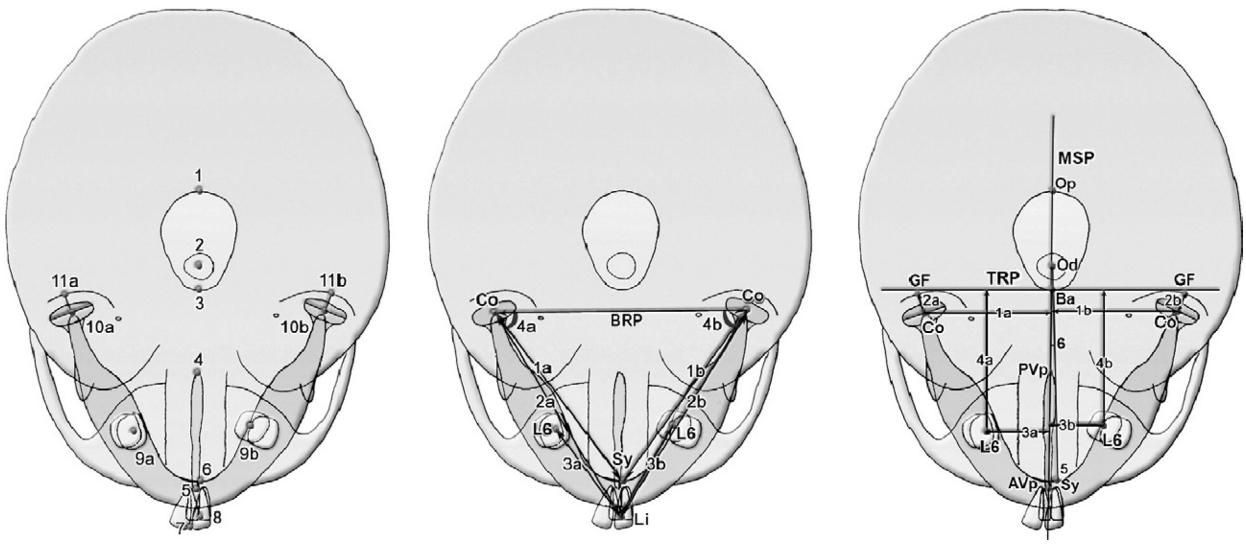

Fig 3. A, Landmarks used in submentovertex cephalometric radiographs (*a,* right side; *b,* left side): *1,* opisthion (Op); *2,* odontoid process (Od); *3,* basion (Ba); *4,* posterior vomer point (PVp); *5,* anterior vomer point (AVp); *6,* symphyseal point (Sy); *7,* upper 1 (U1); *8,* lower 1 (L1); *9,* lower 6 (L6); *10,* condylion (Co); *11,* glenoid fossa (GF). **B,** Morphological measurements of mandible in submentovertex radiographs: *1,* condylion-symphysis distance (Co-Sy); *2,* condylion-mandibular midline distance (Co-L1); *3,* mandibular first molar-mandibular midline distance (L6-L1); *4,* bicondylar reference plane-condylion-symphysis angle (BRP-Co-Sy). **C,** Positional measurements of mandible in submentovertex radiographs: *1,* condylion-midsagittal plane distance (Co-MSP); *2,* condylion-glenoid fossa distance (Co-GF); *3,* mandibular molar-transverse reference plane distance (L6-TRD); *4,* symphysis-midsagittal plane distance (Sy-MSP); *5,* symphysis-basion-midsagittal plane angle (Sy-Ba-MSP).

The following records were obtained from each patient: lateral cephalometric head films, posteroanterior cephalograms, submentovertex radiographs, transcranial TMJ radiographs, joint vibration analysis (with BioPAK version 2.03, Bioresearch Associations, Inc, Milwaukee, Wisc), and EMG of the masticatory muscles (with BioPAK).

The cephalometric radiographs were taken for morphologic evaluation, and the radiographs were taken to determine the position of the condyle in the glenoid fossa. Joint vibration analysis was used to investigate TMJ sounds. EMG analysis was performed if the masticatory muscles were functioning in balance bilaterally during resting and functional movements.

The quad-helix appliance, developed by Ricketts, was made of 0.9-mm stainless steel wire and was activated 5 mm before the banding procedure.[36,44,45] Its arms were held parallel to each other when activated.

Radiographic evaluation

The lateral cephalometric landmarks are shown in Figure 1; the posteroanterior landmarks and measurements are shown in Figure 2.

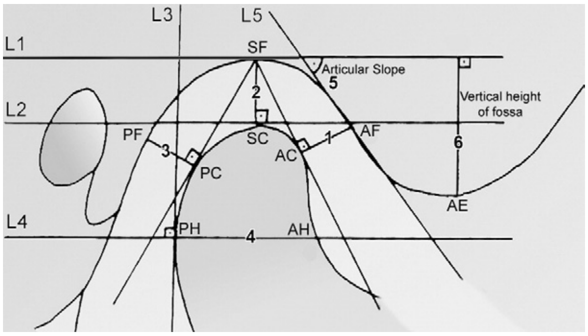

Fig 4. Linear and angular measurements of transcranial TMJ radiographs: *1,* anterior joint space (AJS); *2,* superior joint space (SJS); *3,* posterior joint space (PJS); *4,* condylar width (CW); *5,* articular slope (AS); *6,* vertical height of the fossa (VH).

The landmarks and measurements used to evaluate the submentovertex radiographs are shown in Figure 3. Submentovertex radiographs were taken in intercuspal position with the head positioned perpendicular to the Frankfort horizontal and maintained with a cephalo-

Table I. Lateral cephalometric changes in treatment group before (T1) and after (T2) maxillary expansion compared with control group

	T1	*T2*	*Control*	*Significance T1-T2*	*Significance T1-control*	*Significance T2-control*
Na-Me (mm)	114.79 ± 6.99	119.07 ± 5.78	113.51 ± 5.12	†		†
ANS-Me (mm)	65.86 ± 4.18	68.68 ± 3.83	63.89 ± 3.55	†		†
GoGnSN (°)	31.83 ± 3.26	34.38 ± 4.17	32.19 ± 3.8	†		†
FMA (°)	24.12 ± 2.18	26.10 ± 1.72	24.24 ± 1.22	†		†
ANS-Xi-Pm (°)	47.81 ± 3.06	50.87 ± 2.59	46.49 ± 3.12	*		†
CD (°)	29.81 ± 2.47	29.59 ± 2.53	30.17 ± 2.87			
FT (°)	67.31 ± 2.17	64.46 ± 2.33	66.19 ± 1.98	†		†
FA (°)	87.92 ± 2.23	85.85 ± 3.03	88.64 ± 2.75	†		*
MA (°)	31.68 ± 3.17	32.03 ± 2.82	31.96 ± 2.66			
SNA (°)	80.11 ± 1.62	80.45 ± 1.73	79.83 ± 1.33			
SNB (°)	78.30 ± 1.56	76.52 ± 1.88	78.58 ± 1.36	†		*
ANB (°)	1.81 ± 1.59	3.92 ± 1.67	1.25 ± 1.87	†		*
FD (°)	87.36 ± 2.21	85.19 ± 2.28	88.58 ± 1.78			*
MD (°)	88.69 ± 2.08	89.06 ± 2.18	89.05 ± 1.85			
U1-SN (°)	100.09 ± 3.49	101.32 ± 3.88	100.56 ± 3.78			
U1-FH (°)	110.63 ± 3.53	111.08 ± 3.29	112.09 ± 3.21			
U1-A-Pog (°)	26.96 ± 2.17	27.29 ± 1.99	25.99 ± 2.77			
U1-A-Pog (mm)	3.28 ± 1.46	4.30 ± 1.58	2.75 ± 1.29			
FMIA (°)	63.78 ± 4.61	64.03 ± 4.27	63.61 ± 3.98			
IMPA (°)	90.34 ± 2.88	89.76 ± 2.97	22.58 ± 2.66			
L1-A-Pog (°)	22.55 ± 2.53	25.10 ± 2.82	21.37 ± 2.76	†		†
L1-A-Pog (mm)	3.21 ± 1.02	5.33 ± 1.17	2.04 ± 1.65	†		†
UL-E (mm)	0.51 ± 2.01	2.65 ± 1.92	0.76 ± 1.88	†		†
LL-E (mm)	0.29 ± 1.93	2.00 ± 1.98	0.66 ± 2.16	†		†

*P <.01; †P <.001.

stat. Morphologic asymmetry was measured from the midcondylar reference plane, constructed as the perpendicular bisector of the line joining the right and left condylion (Co) landmarks defining the bicondylar reference plane (BRP). Anteroposterior morphological asymmetry was assessed as each landmark's perpendicular distance from BRP.

The positional asymmetry of the mandible relative to the cranium was evaluated relative to the midsagittal plane (MSP), constructed by using the best-fit line connecting opisthion, basion odontoid, posterior vomer point, and anterior vomer point. The MSP was used to assess transverse asymmetry. The transverse reference plane (TRP), perpendicular to the MSP and passing through the odontoid process, was used to assess anteroposterior positional asymmetry. The perpendicular distances of the lower incisors (LI) and the symphysis (Sy) were measured relative to the midcondylar reference plane and the MSP to compare the morphologic and positional asymmetry of the anterior dental and skeletal structures.

The landmarks used to evaluate the transcranial radiographs are shown in Figure 4. Transcranial TMJ radiographs were obtained to evaluate the position of the condyles. In the transcranial radiograph, line 1 was drawn tangent to the most superior point of the glenoid fossa and parallel to the superior border of radiogram. Line 2 was drawn parallel to line 1 and tangent to the most superior point of the condyle. Then 2 lines were drawn from the most superior point of the glenoid fossa passing tangent to the anterior and posterior condyle points. Perpendiculars to these tangents from the 2 condyle points intersected at the glenoid fossa at points anterior fossa and posterior fossa, respectively. A line was drawn through anterior fossa tangent and best fit to the anterior slope of the glenoid fossa as articular slope. Line 3 was the line drawn perpendicular to horizontal lines and passing through the posterior border of the condyle. Line 4 was drawn parallel to lines 1 and 2 through the most convex point of on the posterior aspect of the condylar head. The intersections of line 4 with the anterior and posterior aspects of the condyle are called theanterior and posterior heads of the condyle, respectively. Articular eminence point showed the most inferior aspect of the crest of the articular eminence.

Magnetic resonance images

The position of the articular disc was evaluated by magnetic resonance imaging performed with Siemens

1.5 T MR scanner (Symphony, Siemens, Erlangen, Germany). Bilateral closed-mouth sagittal sections were obtained perpendicular to the long axis of the condyle, and coronal images were obtained parallel to the condylar long axis. To prevent muscle fatigue, bilateral open-mouth sagittal images were produced by placing an acrylic bite plane set at 10 mm below the maximum voluntary interincisal mouth opening. The subjects were instructed to rest the anterior teeth on the acrylic bite plane. The normal disc position with normal function was determined as the disc located with its posterior band superior to the condyle, with the inferior aspect of the central thin zone of the disc articulating against the anterior prominence of the condyle. The displaced disc establishing its normal relationship with the condyle during mouth opening was referred to as disc displacement with reduction. Disc displacement without reduction was the disc located more anteriorly than its normal position during all mandibular movements.

TMJ vibration analysis

Surface vibrations of the bilateral TMJs were recorded with electrovibratography (EVG) (SonoPAK system, Bioresearch, Milwaukee, Wis). Patients were instructed to perform maximum jaw opening and closing movements guided by an electric metronome signal. The skin surface vibration signals were detected by 2 piezzoelectric accelerometers and sent to a differential amplifier. The attenuated and filtered signal was sampled online at about 4000 sample points by a personal computer attached to an 8-bit AC-DC converter handling 1300 samples per second. The raw signal in the 200-millisecond window was subjected to a fast Fourier transform algorithm with a resolution of 5 Hz that computed the power spectrum density function of the vibration signal.

The following terms were calculated: total intergral (Ti), integral <300 Hz/integral >300 Hz ($</>$ 300 Hz), peak amplitude (PA), peak frequency (PF), and medium frequency (MF).

After running the fast Fourier transform algorithm, the peak and the median frequencies were computed. The peak frequency had the highest amplitude in the power spectrum density function. The median frequency is the frequency that divides the power spectrum density function into 2 regions with equal power. The integral of the EVG is the area under the curve of the power spectrum density function. The ratio of the frequencies below and above 300 Hz is the ratio between the integrals above and below 300 Hz. Peak amplitude is the absolute amplitude of the peak frequency.

EMG evaluation of the masticatory muscles

The temporalis anterior, masseter, sternocleidomastoid, and digastric muscles of both sides were examined. Bipolar surface electrodes were positioned on the muscular bellies parallel to muscle fibers. The electrode on the temporalis anterior muscle was fixed vertically along the anterior margin of the muscle. The masseter electrode was placed parallel to the muscular fibers, with the upper pole of the electrode at the intersection of the targus-labial comissura and exocanthion-gonion lines. The sternocleidomastoid muscle electrode was placed parallel to the muscle fibers on both sides of the neck where the muscle was palpated, especially when the head was rotated. The digastric muscle electrodes were placed bilaterally between the menton-neck line. To reduce the electrode impedance, the skin was carefully cleaned before electrode placement. During testing, disposable silver/silver chloride bipolar electrodes with a diameter of 10 mm and an electrode distance of 20 mm were used; a disposable ground electrode was applied to the right side of the neck. EMG activity was recorded on an 8-channel instrument. The analog EMG signal was amplified with a gain of 150, a bandwidth of 0-10 KHz, and an input range of 0 to 1000 μV (peak to peak) by using a different amplifier with a high common mode rejection ratio (105 dB in the range 0-60 Hz, input impedance 60 GΩ). The signal was digitized (12 dB resolution, 2230 Hz sampling frequency), and digitally filtered (-3 dB) to eliminate the direct current of the electrodes and any other electrical interference. The filters were second-order high-pass (set at 30 Hz) and low-pass (700 Hz) filters and a second-order band-stop filter for common 50-60 Hz $\pm$ 0.025% noise (attenuation 40 dB). The instrument was directly interfaced with a computer that presented the data graphically and recorded them on magnetic media for further quantitative and qualitative analyses. The signals were averaged over 50 ms, with muscle activity of the 8 tested muscles (temporalis anterior right, left temporalis anterior, masseter right, masseter left, digastric anterior right, digastric anterior left, sternocleidomastoid right, and sternocleidomastoid left) assessed as the root mean square of the amplitude (unit: μV). EMG signals were recored for further analysis. EMG activity was recorded at rest position, and during swallowing and maximum clenching.

Error of the method

Measurements were made twice, 1 month apart, to determine the repeatability of landmark identification and measurement techniques. All angular and linear

Table II. Posteroanterior cephalometric changes in treatment group and comparison with control group

	Pretreatment cross-noncross (A)	*Posttreatment cross-noncross (B)*	*Control group right-left (C)*	*Sig A-B*	*Sig A-C*
MR (mm)	5.56 ± 0.43	−0.38 ± 0.54	0.63 ± 0.04	*	*
U6-FP (mm)	3.19 ± 0.23	0.23 ± 0.45	0.75 ± 0.37	*	*
L6-FP (mm)	3.99 ± 0.45	0.43 ±0.45	0.56 ± 0.24	*	*
PSA (°)	2.89 ± 0.74	0.07 ± 0.41	0.77 ± 0.03	*	*
U6 inc (°)	−0.65 ± 0.64	−0.19 ± 0.35	0.75 ± 0.46		
UIMW (mm)					
LIMW (mm)					
U1-MSP (mm)					
L1-MSP (mm)					
U1-L1 (mm)					
Me-MSP (mm)					
AZ-ZA (mm)					
JL-JR (mm)					
TmxA (°)					
TmdA (°)					
TJR (°)					

*P <.001.
A, Difference between crossbite and noncrossbite side values in FPXB group before treatment.
B, Difference between crossbite and noncrossbite side values in FPXB group after treatment.
C, Difference between right and left side values of control group.
T1, Initial; *T2,* end of maxillary expansion; *Sig,* significance.

variables had a coefficiant of intrarater reliability. (r = Σ^2 total/Σ^2 between) between 0.85 and 1.00; thus, this error was considered negligible.

Intragroup and intergroup comparisons were made by using paired sample *t* tests. Statistical analysis was made with a commercial statistical package (SPSS 10.0, SPSS, Chicago, Ill).

RESULTS

The pretreatment and posttreatment lateral cephalometric data and control group values are given in Table I.

The distance and the angles showing the vertical dimensions of the cranium increased with maxillary expansion. The posttreatment values indicating the vertical growth pattern (FMA, GoGnSN, lower facial height angles, and Na-Me and ANS-Me distances) increased significantly (P <.001, Table I).

The pretreatment and posttreatment posteroanterior cephalometric data and control group values are given in Table II.

There were significant differences between the crossbite and noncrossbite sides according to molar relationships, distance between the maxillary molar to facial plane, as well as the mandibular molar to facial plane (P <.001, Table II). With maxillary expansion, the maxillary and mandibular intermolar widths increased significantly (P <.001, Table II). The distances between the mandibular central incisors to midsagittal plane and menton to midsagittal plane decreased significantly, like the decrease in the transmandibular plane angle and transverse jaw relationship angle (P <.001, Table II).

The pretreatment and posttreatment submentovertex radiographic data and control group values are given in Table III.

Before maxillary expansion, the mandible had a generalized pattern of skeletal asymmetry; the crossbite side was significantly smaller than the noncrossbite side (P <.01, Table III). The Co-Sy and Co-L1 distances were significantly longer on the noncrossbite side compared with the crossbite side (P <.01, Table III). The BRP-Co-Sy angle was significantly smaller on the noncrossbite side than on the crossbite side (P <.001, Table III).

After maxillary expansion, no value between the crossbite and noncrossbite sides or the treatment and control groups was statistically significant (P >.05, Table III).

The control group had no significant differences between the 2 sides regarding the Co-Sy and Co-L1 distances and BRP-Co-Sy angle (P >.05, Table III).

The pretreatment and posttreatment transcranial TMJ radiographic data and control group values are given in Table IV.

Before treatment, both the posterior and superior joint spaces were significantly larger on the noncrossbite side and significantly smaller on the crossbite side (P <.001, Table IV). In contrast, the anterior joint pace

Table II. Continued

Sig B-C	*T1*	*T2*	*Control*	*Sig T1-T2*	*Sig T1-control*	*Sig T2-control*
	54.45 ± 2.56	61.36 ± 2.78	59.62 ± 2.78	*	*	
	57.52 ± 2.65	59.66 ± 2.87	58.42 ± 2.53	*		
	0.65 ± 0.48	0.53 ± 0.28	0.49 ± 0.63			
	3.26 ± 2.53	0.49 ± 0.38	0.53 ± 0.39	*	*	
	3.42 ± 2.66	0.57 ± 0.52	0.59 ± 0.52	*	*	
	3.26 ± 2.45	0.79 ± 0.63	0.62 ± 0.42	*	*	
	54.45 ± 2.56	61.36 ± 2.78	59.62 ± 2.78	*	*	
	85.35 ± 3.56	87.35 ± 3.89	86.02 ± 2.36	*		
	64.73 ± 3.42	65.79 ± 3.25	65.13 ± 2.40			
	0.68 ± 1.53	0.52 ± 1.23	0.59 ± 0.42			
	3.58 ± 2.13	0.48 ± 0.15	0.68 ± 0.42	*	*	
	3.74 ± 2.27	0.62 ± 0.27	0.53 ± 0.68	*	*	

was significantly larger on the crossbite side and significantly smaller on the noncrossbite side (P <.01, Table IV). The control group had symmetrically positioned condyles on both sides; there were no significant differences between the right and left TMJ spaces (P >.05, Table IV). The pretreatment values of the treatment group were significantly different from those of the control group (P <.01, Table IV). After treatment, the differences between the joint space measurements were not significant (P >.05, Table IV).

Table V shows the mean values of the EVG findings. Total integral and peak frequency values were significantly higher on the crossbite side compared with the noncrossbite side before treatment (P <.001, Table V). There was no significant difference between the right and left sides of the control group (P >.05, Table V). The differences between the treatment and the control groups were significant for these parameters (P <.001, Table V). After maxillary expansion, both the crossbite and the noncrossbite sides had similar values, and there was no significant difference between the treatment and control groups (P >.05, Table V).

Muscular activity at rest position

Table VI shows the mean values and standard deviations of electric potentials recorded from the 8 examined muscles at rest position. The anterior temporal and masseter muscle activities were significantly different (P <.001, Table VI) in the treatment and control groups. In the normocclusive children, there was no significant difference between the right and left sides during resting (P >.05, Table VI). In the FPXB group, the anterior temporal and masseter muscles showed significantly higher activities on the crossbite side compared with the noncrossbite side at rest before treatment (P <.001, Table VI). After maxillary expansion, the difference between the 2 sides was eliminated, and the muscle activities were balanced with no significant differences between the 2 groups (P >.05, Table VI). There were no statistically significant differences in the activities of the sternocleidomastoid and digastric muscles between the crossbite and noncrossbite sides in treatment group, the right and left sides in the control group, and the treatment and control groups (P <.05, Table VI).

Muscular activity during swallowing

The average EMG values during swallowing are shown in Table VI. There were no statistically significant differences in the activities of any masticatory muscles between the crossbite and noncrossbite sides in treatment group (P >.05, Table VI), the right and left sides in the control group (P >.05, Table VI), and the treatment and control groups (P >.05, Table VI).

Muscular activity during maximum clenching

Significant differences were found between both groups during clenching (P <.001, Table VI). At the crossbite side, the anterior temporalis muscle showed a significantly higher EMG value than the noncrossbite side before treatment (P <.001, Table VI). The right and left sides of the control group showed no significant difference during clenching (P >.05, Table VI). The differences between the treatment and control groups were significant (P <.001, Table VI). On the contrary,

Table III. Submentovertex radiographic changes in treatment group and comparison with control group

	Pretreatment cross-noncross (A)	*Posttreatment cross-noncross (B)*	*Control group right-left (C)*	*Sig A-B*	*Sig A-C*
Co-Sy (mm)	2.44 ± 1.13	0.88 ± 0.27	0.30 ± 0.32	*	†
Co-L1 (mm)	2.42 ± 0.57	0.95 ± 0.32	0.88 ± 0.65	*	*
L6-L1 (mm)	0.83 ± 0.35	0.43 ± 0.31	0.58 ± 0.05		
BRP-Co-Sy (°)	2.22 ± 1.86	0.58 ± 0.42	0.34 ± 0.09	†	†
Co-MSP (mm)	1.68 ± 0.53	0.32 ± 0.12	0.27 ± 0.12	*	*
Co-GF (mm)	1.83 ± 0.58	0.53 ± 0.23	0.31 ± 0.67	*	†
L6-MSP (mm)	2.35 ± 0.92	0.72 ± 0.18	0.45 ± 0.22	†	†
L6-TRP (mm)	2.28 ± 0.84	0.72 ± 0.75	0.37 ± 0.26	†	†
Sy-MSP (mm)					
Sy-Ba-MSP (°)					

*$P < .01$; †$P < .001$.
A, Difference between crossbite and noncrossbite side values in FPXB group before treatment.
B, Difference between crossbite and non crossbite side values in FPXB group after treatment.
C, Difference between right and left side values of control group.
T1, Initial; *T2,* end of maxillary expansion; *Sig,* significance.

Table IV. Transcranial TMJ radiographic changes in treatment group and comparison with control group

	Pretreatment cross-noncross (A)	*Posttreatment cross-noncross (B)*	*Control group right-left (C)*	*Significance A-B*	*Significance A-C*	*Significance B-C*
AJS (mm)	−1.78 ± 0.45	0.52 ± 0.58	0.25 ± 0.12	†	†	
SJS (mm)	1.45 ± 0.35	0.43 ± 0.42	−0.42 ± 0.14	†	*	
PJS (mm)	1.37 ± 1.02	0.62 ± 0.34	0.39 ± 0.04	*	*	
CW (mm)	−0.83 ± 0.34	−0.69 ± 0.58	0.99 ± 0.34			
AS (°)	−0.17 ± 0.11	0.22 ±0.34	0.29 ± 0.53			
VH (mm)	−1.78 ± 0.53	0.52 ± 0.43	0.25 ± 0.12			

*$P < .05$; †$P < .01$.
A, Difference between crossbite and noncrossbite side values in FPXB group before treatment.
B, Difference between crossbite and noncrossbite side values in FPXB group after treatment.
C, Difference between right and left side values of control group.

Table V. Joint vibration analysis changes in treatment group and comparison with control group

	Pretreatment cross-noncross (A)	*Posttreatment cross-noncross (B)*	*Control group right-left (C)*	*Significance A-B*	*Significance A-C*	*Significance B-C*
Ti (Hz)	−3.73 ± 0.58	−0.42 ± 0.43	0.27 ± 0.04	‡	‡	
</>300 Hz (Hz)	0.57 ± 0.43	0.11 ± 0.45	0.61 ± 0.43			
PA (Hz)	−0.04 ± 0.42	−0.24 ± 0.37	−0.21 ± 0.15			
PF (Hz)	−3.47 ± 0.45	0.17 ± 0.34	0.91 ± 0.53	†	†	
MF (Hz)	10.53 ± 3.25	−0.01 ± 0.11	−0.05 ± 0.02	‡	*	

*$P < .05$; †$P < .01$; ‡$P < .001$.
A, Difference between crossbite and noncrossbite side values in FPXB group before treatment.
B, Difference between crossbite and noncrossbite side values in FPXB group after treatment.
C, Difference between right and left side values of control group.

masseter muscle activity was significantly higher on the noncrossbite side before treatment, and the difference between the treatment and control groups was significant ($P < .001$, Table VI). After maxillary expansion, there were no significant differences between the treatment and control groups in masseter muscle activity ($P > .05$, Table VI). There were no statistically significant differences in the activities of the sternocleidomastoid and digastric muscles between the crossbite and noncrossbite side in treatment group, the right and left sides in the control group, and the treatment and control groups ($P > .05$, Table VI).

The magnetic resonance imaging records were taken at the beginning of treatment. In the treatment group, 8 patients (22.85%) had unilateral disc displacement with reduction, 2 (5.32%) had bilateral disc

Table III. Continued

Sig B-C	*T1*	*T2*	*Control*	*Sig T1-T2*	*Sig T1-control*	*Sig 2-control*
	2.76 ± 1.92	0.73 ± 0.36	0.79 ± 0.32	†	†	
	2.81 ± 1.59	0.88 ± 0.53	0.53 ± 0.29	†	†	

displacement with reduction, and 1 (3.86%) had bilateral disc displacement without reduction. Another 24 patients (68.57%) had normal condyle-disc relationships. In the asymptomatic control group, 6 children (19.35%) had unilateral disc displacement with reduction,1 child (3.23%) had bilateral disc displacement with reduction, and 1 (3.23%) had bilateral disc displacement without reduction. Twenty-three children (74.19%) had normal condyle-disc relationships.

DISCUSSION

Correction of FPXB in the mixed dentition as early as possible after diagnosis has been recommended.[3,5,9,15,22,24,33,34,40,44,45] FPXB, if left untreated, can have deleterious effects on the development and function of the TMJs. The lateral shift of the mandible observed on closure can cause displacement of the condyle on the affected side, thus disturbing the equilibrium between form and function of the joint. Because of the compensation of the asymmetric condyle position in later in life, FPXB can cause craniofacial asymmetry. Subsequent adaptation of the neuromusculature to the acquired mandibular position can cause asymmetric mandibular growth, facial disharmony, and severe skeletal crossbite with permanent distortion. In this study, we treated patients with FPXB in the mixed dentition to prevent asymmetry because early treatment is recommended.[3,5,9,15,22,24,33,34,40,44,45] After treatment, the correction of the crossbite led to bilateral symmetry. Maxillary expansion with the quad-helix appliance is suggested as an effective treatment choice.[34,46-53]

In our study, Na-Me and ANS-Me distances, and the FMA, GoGnSN, and lower facial height angles increased significantly after maxillary expansion ($P < .001$, Table I). These findings are related to the posterior rotation of the mandible caused by the buccal tipping of the maxillary first molars.[50] This agrees with the findings of Tindlund et al[54] and Silva Filho et al,[36] who reported downward and backward rotations of the mandible after maxillary expansion, and with other studies showing posterior rotations of the mandible.[55-59]

In the posteroanterior cephalograms before treatment, molar relationship, the distance of the maxillary molars to the facial plane, and the positional symmetry angle showed significant differences ($P < .001$, Table II) between the crossbite and noncrossbite sides, indicating that the mandible was asymmetrically positioned relative to the craniomandibular structures. After maxillary expansion, the differences between the 2 sides were eliminated. In addition, mandibular dental midline-midsagittal plane distance, the transverse distance between the maxillary and mandibular dental midlines, the transverse mandibular position angle, and the transverse jaw relationship angle decreased significantly ($P < .001$, Table II), proving the effectiveness of maxillary expansion treatment in eliminating the functional shift and correcting the positional asymmetries. The maxillary first molars were tipped buccally. This agrees with the findings of Hesse et al,[22] Haas,[60,61] Wertz,[55] Brin et al,[62] Gryson,[63] Erdinç et al,[39] Hicks,[64] Cotton,[65] and Herold.[66] After maxillary arch expansion, mandibular arch width had an autonomous increase with the maxillary expansion. This association was related to the alterations in the occlusion, providing lateral forces as canine contacts moved from the fossae of opposing teeth to canine inclines and to widening of the area attachment of the buccal musculature, changing the balance with tongue pressure. Our study confirmed that mandibular intermolar width increases spontaneously with maxillary expansion.[55,60,61] Facial width did not show a significant increase ($P > .05$, Table II), but the increase was within normal limits of growing as reported by Ricketts.[50] This agrees with the findings of Ben-Bassat et al[14] and Lux et al.[67]

According to the submentovertex radiographs, our results showed that the mandibles of the children with

Table VI. Electromyographic changes in treatment group and comparison with control group during resting, swallowing, and maximum clenching

	Pretreatment cross-noncross (A)	*Posttreatment cross-noncross (B)*	*Control group right-left (C)*	*Significance A-B*	*Significance A-C*	*Significance B-C*
Resting						
AT (μV)	−2.09 ± 1.28	−0.27 ± 0.53	−0.22 ± 0.45	†	†	
MM (μV)	−1.73 ± 0.27	0.20 ± 0.27	−0.55 ± 0.24	*	*	
SCM (μV)	0.09 ± 0.25	0.22 ± 0.24	−0.04 ± 0.43			
DA (μV)	0.21 ± 0.43	−0.11 ± 0.18	0.08 ± 0.22			
Swallowing						
AT (μV)	−2.09 ± 1.28	−0.27 ± 0.53	−0.22 ± 0.45	†	†	
MM (μV)	−1.73 ± 0.27	0.20 ± 0.27	−0.55 ± 0.24	*	*	
SCM (μV)	0.09 ± 0.25	0.22 ± 0.24	−0.04 ± 0.43			
DA (μV)	0.21 ± 0.43	−0.11 ± 0.18	0.08 ± 0.22			
Maximum clenching						
AT (μV)	−2.97 ± 0.43	−0.06 ± 0.02	0.68 ± 0.36	†	†	
MM (μV)	3.25 ± 1.37	0.63 ± 0.03	0.33 ± 0.23	†	†	
SCM (μV)	−0.40 ± 0.44	0.11 ± 0.18	−0.25 ± 0.37			
DA (μV)	0.33 ± 0.15	0.31 ± 0.17	0.14 ± 0.34			

*P <.01; †P <.001.

A, Difference between crossbite and noncrossbite side values in FPXB group before treatment.

B, Difference between crossbite and noncrossbite side values in FPXB group after treatment.

C, Difference between right and left side values of control group.

FPXB were asymmetrically displaced in the intercuspal position with a significant midline deviation toward the crossbite side. The displaced Sy L6 and Co points indicated mandibular deviation. This positional deviation was in both the lateral and anteroposterior directions. Lateral mandibular shift is well established for FPXB,[13,14,28,44,68,69] but anteroposterior displacement is rarely investigated.[14,25,28] Our results suggested that positional asymmetry produces mandibular skeletal asymmetry, especially affecting the ramus with the crossbite side being shorter than the noncrossbite side. The distances between Co-Sy and Co-Li increased significantly during treatment (P <.001, Table III). The vertical distances of L6 and Co to the BRP increased significantly more on the crossbite side (P <.001, Table III). The horizontal distances of L6 and Co to BRP increased on the noncrossbite side and decreased on the crossbite side, indicating that the mandible shifted toward the noncrossbite side during maxillary expansion treatment (P <.001, Table III). The morphologic asymmetry might be the adaptation associated with postural adjustments. Studies on animals showed that the occlusion forced into crossbite malocclusions by occlusal grinding or splints developing asymmetric growth patterns results in asymmetric changes in the condylar region.[44,46,69,70] The adaptive mechanisms for the noncrossbite side condyles are similar to those proposed for functional appliances stimulating condylar growth. Because the mandible is positioned anteriorly, medially, and inferiorly to the crossbite side, the anterior side of ramus and Co might adapt by posterior drift. Our results show that, with maxillary expansion, the skeletal and positional asymmetries were eliminated. In contrast to the studies,[15,22] our study showed that maxillary expansion changes the position of the condyles and improves skeletal asymmetries.

The transcranial TMJ radiographic results showed that the asymmetric mandibular position caused asymmetric condylar joint spaces. The condyle on the noncrossbite side was positioned inferiorly and anteriorly relative to the condyle on the crossbite side. Myers et al[15] reported large superior and anterior joint spaces on the noncrossbite side. Hesse at al[22] showed that displacement occurred as the mandible moved along the eminence, with large superior and posterior joint spaces on the noncrossbite side. However, Nerder et al[71] reported normally centered condyles in 6 children with unilateral posterior crossbites. Because of the small sample size and the unilateral posterior crossbites, not FPXB, this finding is thought to be insufficient.

TMJ sounds, reported in several studies,[72-76] are a common symptom in patients with TMJ dysfunction.[72,77] Our study showed that the total integral, peak frequency, and medium frequency values were higher on the crossbite side than on the noncrossbite side (P <.001, Table V). The difference between the treatment and control groups before treatment was decreased with treatment, and the joint vibrations were within normal limits. Christensen and Orloff[78] mentioned that subjects with TMJ sounds clinically had higher values of median frequency, peak frequency, and peak amplitude. Our findings are similar to those results. Olivieri et al[79] reported that symptomatic patients had higher vibration energies than asympotomatic ones during mandibular movements.

We found large standard deviations relative to the mean values of EMG activity in both the normocclusive and FPXB groups. This finding agrees with other studies,[80-82] probably due to the great biological variability of subjects. Children with FPXB have greater postural activity of the anterior temporalis muscles on the noncrossbite side, indicating positional asymmetry.[25,29,30] Those with habitual asymmetry might be expected to develop skeletal asymmetries.

We found that the resting activities of the masseter and anterior temporalis muscles were significantly higher on the crossbite side compared with the noncrossbite side and the control group values (P <.001, Table VI). These results agree with those of Troelstrup and Moller,[30] Ingervall and Thilander,[31] and Haralabakis and Loufty.[29] Mandibular lateral shift is believed to be the main cause of the abnormal muscle activity.[40,83]

The magnetic resonance imaging findings showed that TMJs with no apparent TMJ disorderare associated with a high rate of disc displacements. In the FPXB, 24 patient (68.57%) had normal condyle-disc relationships, 8 (22.85%) had unilateral disc displacement with reduction, 2 (5.32%) had bilateral disc displacement without reduction, and 1 (68.57%) had disc displacement without reduction. In the control group, 23 subjects (74.19%) had normal disc-condyle relationships, 6 (19.35%) had unilateral disc displacement with reduction, 1 (3.23%) had bilateral disc displacement without reduction, and 1 (3.23%) had bilateral disc displacement without reduction. This finding is consistent with those of other studies.[84-86] TMJ internal derangement alone might not always be associated with pain and dysfunction, and several imaging studies also demonstrated bilateral TMJ internal derangements with frequencies of 51% to 71%.[87-89]

CONCLUSIONS

The following conclusions can be made.

1. The mandibles in patients with FPXB were rotated relatively posteriorly on the crossbite side related to the cranial floor, causing the condyle to be asymmetrical in the glenoid fossae. Pretreatment condylar positions were asymmetric due to the anterior and inferior position of the noncrossbite side condyle and posterior and superior position of the crossbite side condyle.
2. Due to the functional shift, the mandible was deviated toward the crossbite side transversely.
3. After treatment, the establishment of more symmetry through posterior and superior movement of the noncrossbite side condyle and anterior and inferior movement of the crossbite side condyle was possible.
4. Disc displacement of the TMJ was seen in approximately 22% to 27% of the subjects in the FPXB and control groups, respectively. This result shows that clinical examination only is generally insufficient for the diagnosis of TMJ problems.
5. EMG recordings of the masseter and anterior temporalis muscles during rest, swallowing, and clenching showed differences between both groups. Unbalanced masticatory muscle activity improves with the elimination of the mandibular shift.
6. TMJs with FPXB had higher vibration energy than those of the control group. The similar joint vibration analysis values bilaterally after maxillary expansion in both the treatment and control groups indicate the importance of early intervention of FPXB.
7. The aim of early orthodontic treatment is to create optimum conditions for normal growth and development by eliminating the lateral forced bite.[47-52]

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