Changes in jaw movement and jaw closing muscle activity after orthodontic correction of incisor crossbite

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The possible influences of the direction of occlusal loading delivered to the incisors in the sagittal direction during chewing on jaw movement and jaw closing muscle activity were investigated. Ten healthy children with crossbite of one or two incisors on the right side were selected. Each subject chewed a piece of chewing gum on the right side, and jaw displacements and electromyographic signals from the posterior temporalis and superficial masseter muscles on the ipsilateral side were sampled simultaneously. After orthodontic correction of the incisor crossbite relationship, identical records were taken. The inclinations of the gliding contacts for each posterior tooth in the lateral jaw excursion position were consistent before and after the treatment. The posttreatment records showed broader jaw movement patterns in the frontal view and faster jaw movement velocity in the lateral direction at a level close to the habitual maximum intercuspation position, when compared with the pretreatment records ($P < 0.05$). The duration of the muscle activity and the incidence of the silent periods of the masseter muscle during chewing significantly decreased after the treatment ($P < 0.05$). The current results give a neurophysiologic rationale for explaining the significance of orthodontic treatment in improving lowered masticatory efficiency in the way that the change in direction of the occlusal load achieved by tooth movement influences on the periodontal sensory input, which, in turn, modifies the trigeminal motor output and thus, eventually, jaw muscle activities. (Am J Orthod Dentofac Orthop 1997;112:403-9.)

Crossbite relationship of one or two incisors with the opposing teeth is frequently seen in orthodontic practice, but our knowledge of the neurophysiologic rationale for its treatment has been limited. In clinical studies by Michler et al.[1] and Proschel and Hofmann,[2] human subjects whose molar relationship between the maxilla and the mandible were in either crossbite or Angle Class III relationships, showed more chopping jaw movement patterns, when compared with those with no crossbite and Angle Class I relationships. However, the results did not explain the cause neurophysiologically. Hannam et al.[3] and Takada[4] have reported that the jaw movement pattern during chewing was altered by the presence of occlusal interferences on posterior teeth and malocclusions.

The trigeminal motor output during mastication is centrally regulated,[5,6] but periodontal pressoreceptors of posterior teeth are known to provide positive feedback to the jaw closing muscles during chewing.[7-9] This mechanism acts to increase jaw closing muscle activity during occlusal loading, jaw closing, and the intercuspal phase of a chewing cycle to facilitate comminution of foods. Transient stops of jaw closing muscle activity, i.e., silent periods, are induced by mechanical stimuli to the incisors or electrical stimuli to the muscles.[10,11] Silent periods are also generated by the presence of early incisor contacts during chewing.[12] Teeth are known to be more sensitive to nonaxial forces than those directed along the long axis of the teeth.[13] The chewing force vector applied to the incisors with a crossbite relationship has a nonaxial component, in the sagittal direction, opposite to that seen in a positive overjet relationship. Accordingly, it can be speculated that such difference in the direction of the nonaxial component of the chewing force vector could influence on the trigeminal motor output to the jaw closing muscles. Evans and Lewin[14] have reported that the loss of the peripheral input from periodontal mechanoreceptors as a result of the extraction of lower incisors does not appear to have a consistently significant effect on the characteristic habitual jaw movement pattern. But, the effects of the sensory input from the periodontal mechanoreceptors of the

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Table I. Summary of subjects

Age	*Sex*	*Crossbite*	*Appliance*	*Treatment period*
12Y5M	F	$\frac{2}{21}\Big\rvert$	Edgewise	8M
9Y1M	F	$\frac{2}{c}\Big\rvert$	Lingual arch	13M
10Y2M	F	$\frac{2}{2}\Big\rvert$	Edgewise	13M
12Y0M	F	$\frac{2}{2}\Big\rvert$	Lingual arch	15M
10Y7M	F	$\frac{2}{3}\Big\rvert$	Active plate	6M
8Y2M	M	$\frac{2}{2}\Big\rvert$	Lingual arch	13M
8Y1M	M	$\frac{1}{21}\Big\rvert\Big\lvert\frac{1}{12}$	Active plate	6M
11Y3M	F	$\frac{2}{3}\Big\rvert\Big\lvert\frac{2}{2}$	Edgewise	3M
11Y6M	M	$\frac{21}{21}\Big\rvert\Big\lvert\frac{2}{2}$	Lingual arch	10M
11Y2M	M	$\frac{2}{32}\Big\rvert\Big\lvert\frac{2}{12}$	Edgewise	16M

incisor teeth on jaw movement and jaw closing muscle activity during chewing have not yet been fully elucidated.

The purpose of the current study was therefore to examine possible influences of the direction of occlusal loading delivered to the incisors in the sagittal direction on human jaw movement pattern and jaw closing muscle activity during chewing, before and after orthodontic treatment for correction of incisor crossbite.

SUBJECTS AND METHODS

Subjects

Ten healthy children (4 boys and 6 girls, mean age 10 years, 5 months, SD 18 months: pretreatment stage), with Angle Class I molar relationships and one or two upper right incisors in crossbite relationship with the opposing teeth, were selected. All subjects had intact mixed dentitions and no clinical signs or symptoms of temporomandibular joint dysfunction. They and their parents had received full explanations of the aims and designs of the study before starting of the investigation and consents were obtained.

Orthodontic Treatment for Correction of Incisor Crossbite

All the subjects received orthodontic treatment over a mean period of 11.1 months (SD, 3.2 months). Appliances used to correct the incisor teeth with crossbite relationship were lingual arches with finger springs (four children), active plates (two children), and edgewise appliances (four children) (Table I). The posttreatment stage materials were recorded within 2 or 3 months of finishing the orthodontic treatment. Functional occlusal contacts on the posterior teeth before and after the orthodontic treatment were recorded. The operator hand-guided the patient's lateral occlusal contact movements from the habitual intercuspal position.[15] Inclinations of the functional occlusal contacts thus recorded for each upper posterior teeth were assumed to represent the direction of the occlusal loading to the teeth when shearing foods and were divided into two categories, according to the mediolateral direction of the occlusal force component.[16] All patients exhibited a linguobuccally directed horizontal component of the chewing load to the upper posterior teeth for both the pretreatment and posttreatment records.

Test Food

Hard-type chewing gum (35 × 20 × 2 mm, Ezaki Glico, Osaka) was used for the current study. Its effect as an occlusal load on chewing performance has been reported elsewhere.[17]

Data Recording and Analyses

Experimental paradigms were tested before and after orthodontic treatment of incisors with crossbite relationship. The experimental implementation, including data recording and processing by means of customized software, have been recently described in detail.[9,18] Each subject was seated in an upright but relaxed position, with the head unsupported and naturally oriented. Movement of a lower incisor point in space was recorded by means of a noninvasive transducer (Mandibular Kinesiograph K-5, Myotronics Inc.). The position of a magnetic transducer attached to the labial surfaces of the lower central incisors at the habitual maximum intercuspation position (centric occlusion: CO) was placed at zero to the origin. The magnetometers on a light frame were aligned with a face-bow, so that the horizontal plane was parallel to the Frankfort horizontal and at a right angle to the midsagittal and the frontal planes, and the midsagittal plane and the frontal planes were arranged in space to meet with the origin.[19] Beckman-type paired silver surface electrodes (NT-213U, Nihon-Kohden) with an interelectrode distance of 10 mm were fixed in place in the direction of muscle fibers to record the electromyographic activity from the posterior part of the temporalis (PT) and the superficial part of the masseter (SM) muscles on the right side (Fig. 1). A ground electrode (NM-511S, Nihon-Kohden) was secured to the right wrist. The input stages provided an input resistance differential of 180 M Ω and a common resistance of 1000 M Ω. Each amplifier had a 3 dB-point frequency of 0.08 Hz and 10 KHz. The common mode rejection under the operating conditions was better than 80 dB at 60 Hz. Artifacts were filtered at frequencies of 15 Hz and 3 KHz.

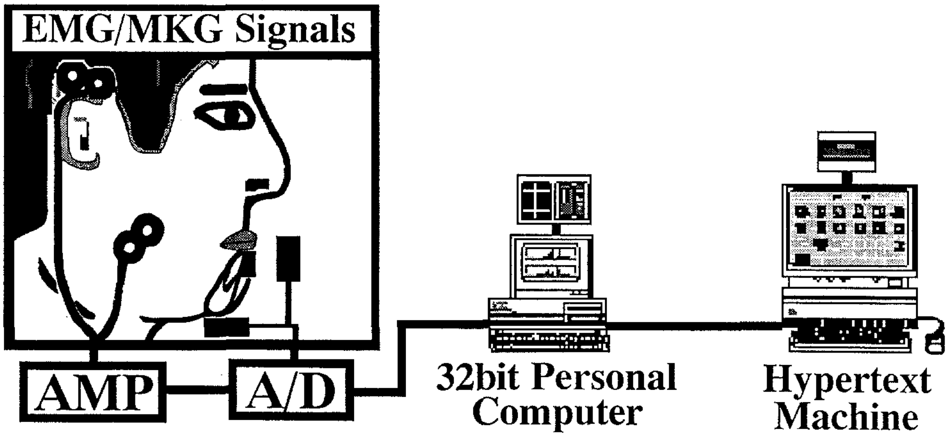

Fig. 1. System block diagram.

Table II. Means and standard deviations of the durations of each chewing phase and jaw positions in the closing phase, and probabilities for significance of mean difference between the pretreatment and posttreatment stages

Duration and jaw position	*Pretreatment*		*Posttreatment*		*Probability*
	Mean	*SD*	*Mean*	*SD*	
Duration					
COout-MOP(ms)	238	72	220	49	0.2665
MOP-COin1(ms)	247	62	225	47	0.1777
COin1-COout1(ms)	248	46	235	38	0.4635
COout1-COout2(ms)	733	112	680	111	0.1317
Position					
COin 3mm Lat(mm)	1.8	1.1	2.4	1.2	0.1298
COin 1mm Lat(mm)	0.7	0.6	1.1	0.5	0.0454
COin 3mm A/P(mm)	−1.3	0.8	−1.4	0.5	0.6787
COin 1mm A/P(mm)	−0.5	0.3	−0.5	0.3	0.7804

Table III. Means and standard deviations of the jaw movement velocities (mm/s) in space determined at specific jaw positions in the closing phase during chewing of a hard chewing gum, and probabilities for significance of mean difference between the pretreatment and posttreatment stages

Jaw position	*Pretreatment*		*Posttreatment*		*Probability*
	Mean	*SD*	*Mean*	*SD*	
COin 3mm					
Lat	−24.9	−13.4	−30.1	−17.1	0.2323
A/P	29.2	18.0	31.7	13.4	0.6501
Ver	52.7	17.4	50.2	18.1	0.7329
COin 1mm					
Lat	−7.3	−6.8	−11.6	−8.1	0.0028
A/P	10.6	7.8	7.8	5.0	0.2945
Ver	21.0	8.3	19.5	6.8	0.6429

Experiment

Each subject chewed a piece of chewing gum on the right side at a pitch that felt natural and comfortable. A computer (PC-386GS, Epson) sampled biosignals from the sixth chewing cycle for five data channels (three jaw displacements and two electromyography (EMG)) automatically at 2KHz. Data recording was continued until the computer counted 30 chewing strokes. Because jaw movement signals showed nonlinear distortion, they were corrected to a mean estimation error of 0.16 mm by means of a nonlinear interpolation method.[20] The digitized biosignals of muscle activity were full-wave rectified, averaged with a moving interval of 1 ms and a window time of 5 ms. They were transferred to a biosignal database,[21] implemented in a hypertext machine (Quadra 800, Apple) for subsequent analyses.

The jaw movement data were checked visually on the computer monitor for rejecting deviant strokes that were often caused by swallowing saliva or chewing gum relocations. Chewing strokes were categorized into medial-out and lateral-out type chews, according to the pattern of jaw movement trajectories on the frontal plane. When the lateral jaw position on jaw opening at the slice level 1 mm below the CO position was equal or medial to the position on jaw closing at the same slice level, the stroke was termed as a *medial-out type chew*. The reversed situation was defined as a *lateral-out type chew*. The incidences of the medial-out type chews were calculated. Each masticatory cycle was automatically divided into open, close, and intercuspal phases. The slice level to determine the beginnings of the open and intercuspal phases was defined as the vertical jaw position of 1 mm below the CO position. The beginning of the jaw closing phase was defined as the period of the maximum jaw opened position (MOP).

As for the jaw movement variables, durations of the opening, closing, and intercuspal phases and duration of a chewing cycle were measured. Positions and velocities of the lower incisor point during chewing at the jaw positions of 1 mm and 3 mm below the CO position and the lower incisor position at the MOP were calculated for each

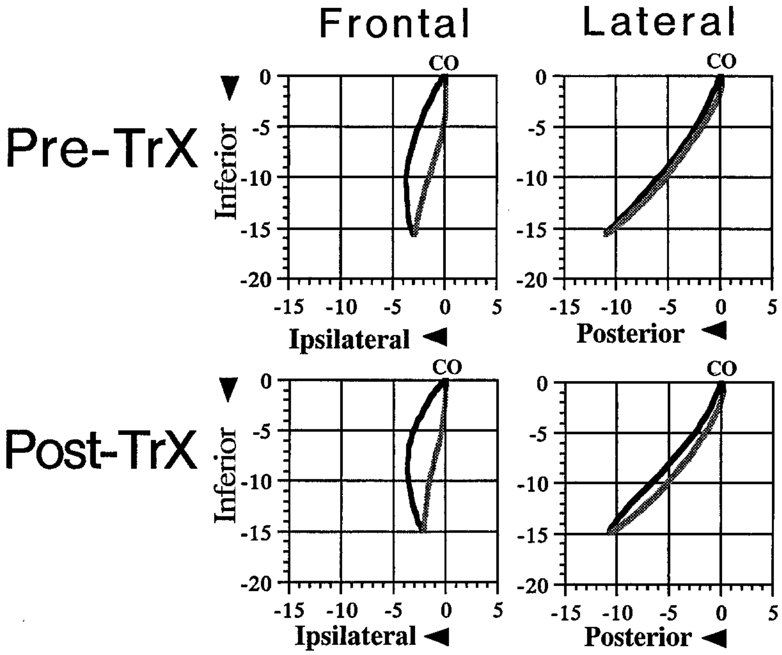

Fig. 2. Mean movement trajectories of lower incisor point during gum chewing on right side (number of subjects, 10). Top, pretreatment stage; bottom, posttreatment stage; left, frontal view; right, lateral view; *gray lines*, opening phase; *black lines*, closing and intercuspal phases; *CO* represents habitual maximum intercuspation position. Slice level was adjusted to 1 mm below CO position. Unit, mm. For details, see text.

Table IV. Medians, minima and maxima of the incidence of silent periods and the duration of muscle activities determined for the posterior part of temporalis and superficial masseter muscles during chewing of a hard chewing gum, and probabilities for significant difference between the pretreatment and posttreatment stages

	Pretreatment			*Posttreatment*			
EMG parameter	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*	*Probability*
PT							
SP(%)	8.7	0.0	35.7	7.4	0.0	24.1	0.3105
Duration (ms)[a]	389	279	583	304	210	698	0.2026
SM							
SP(%)	13.4	0.0	59.1	5.5	0.0	27.3	0.0499
Duration (ms)[a]	358	243	495	305	240	352	0.0093

[a] Duration of muscle activity in a chewing cycle.

masticatory cycle. As for the EMG variables, the duration of the EMG burst was measured for each chewing cycle, and incidence of silent periods in EMG records was calculated for each muscle. The method for measuring silent periods is described in detail elsewhere.[12] All measurements were performed automatically. Values for these variables were computed for each masticatory cycle, and the mean cycle duration of the medial-out type chews was calculated for each subject. Also, jaw displacement records were further processed to determine mean trajectories in three dimensions. Each of the aforementioned three phases was divided into 25 equally spaced time points, and mean jaw displacements and mean EMG amplitudes normalized by peak amplitude at corresponding phase-points were calculated, and durations between aforementioned time points were also calculated by the mean cycle durations for each subject, to understand the overall temporal changes in jaw movement patterns and EMG in a masticatory cycle.

Statistical Analyses

We adopted a paired t test for comparison of paired data, which were taken at the two consecutive treatment stages (pretreatment and posttreatment), except for the variables that were expressed in the form of proportion or EMG time variables.[9] For the proportion and EMG time variables, the Wilcoxon test for paired observations was used. The probability of $P \geq 0.05$ was assumed as not significant. These tests were carried out with statistical analysis software (StatView II, Abacus Concepts, Inc.).

RESULTS

Regarding the incidences of the medial-out type strokes, there was no significant difference between pretreatment and posttreatment stages (pretreat-

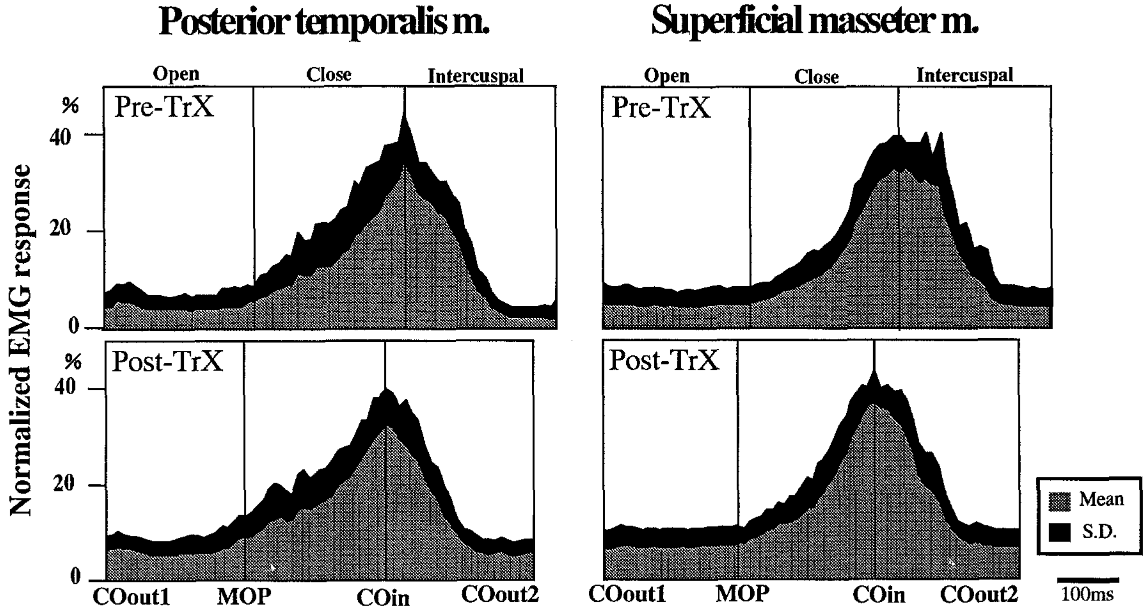

Fig. 3. Mean responses of posterior part of temporalis muscle (left) and superficial masseter muscle (right) during gum chewing on right side in pretreatment (top) and posttreatment (bottom) stages (number of subjects, 10). Vertical lines represent EMG amplitude normalized by peak amplitude, and horizontal lines indicate time axes that consisted of opening, closing, and intercuspal phases. *COout*, beginning of jaw opening phase; *MOP*, time of maximum jaw opening position during chewing; *COin*, end of jaw closing phase. Unit, % for normalized EMG amplitude; *gray*, mean; *black*, +1 SD.

ment: median, 89; minimum, 72; maximum, 100. posttreatment: median, 93; min., 62; max., 100). Comparisons of the durations of each chewing phase, a chewing cycle, and the jaw positions in space between the two treatment stages are given in Table II. Significant differences were not determined between the pretreatment and posttreatment stages for the duration variables. As for the jaw positions, however, lateral jaw displacements on jaw closing for the posttreatment stage at 1 mm below the CO position were significantly more on the chewing side than that of the pretreatment stage ($P < 0.05$). In contrast to the lateral directions, significant differences were not determined for the anteroposterior and vertical distance measurements between the pretreatment and the posttreatment stages.

Jaw movement velocities in space determined at specific jaw positions during chewing are provided in Table III. The jaw movement velocity for the posttreatment stage in the lateral direction at the vertical position 1 mm below the CO position in the closing phase was significantly faster than that of the pretreatment stage (Fig. 2).

Table IV provides medians, minima, and maxima for the incidence of silent periods and the duration of muscle activity, and the probabilities for significant difference between the pretreatment and posttreatment stages. The duration of the superficial masseter muscle burst in the posttreatment stage was significantly shorter, when compared with that of the pretreatment stage. The incidence of the silent periods of the superficial masseter muscle of the posttreatment stage was significantly lower than that of the pretreatment stage. In contrast to the superficial masseter muscle, there were no significant differences concerning the posterior temporalis muscle (Fig. 3).

DISCUSSION

The majority of the strokes that the subjects showed in the pretreatment and posttreatment stages were the medial-out type strokes on the frontal view. A similar high incidence of the medial-out type strokes has been observed in children with good occlusion when chewing gummy jelly.[9] We confirmed that the inclinations of the gliding contacts for each posterior tooth in the guided lateral jaw excursion position were consistent and Angle Class I molar relationships had not changed after the orthodontic treatment. Accordingly, it would be reasonable to assume that the horizontal component of the chewing force to the upper posterior teeth in the early intercuspal phase was linguobuccally directed before and after treatment. Therefore we were able to examine the influences of the direction of occlusal loading delivered to the incisors in the sagittal direction on human jaw movement pattern and jaw closing muscle activity during chewing in the current experiment.

Only lateral jaw displacement and lateral jaw movement velocity at the vertical position 1 mm below the CO position in the closing phase changed significantly in the posttreatment stage. The results suggest that the sensory input from the periodontal mechanoreceptors of the incisor in children with incisor crossbite may influence the mandibular movement at a level close to where teeth may meet and where the loads are increased. Regarding the influence of the direction of occlusal loading delivered to the incisors in the sagittal direction on jaw closing muscles, the duration of the superficial masseter muscle activity decreased significantly after crossbite correction of the incisor. This finding may be consistent with a previous report where it was documented that the duration of the elevator muscle activity during chewing was inversely proportional to the stability of functional occlusion.[22] The incidence of silent periods in the superficial masseter muscle decreased significantly after the crossbite correction.

The decrease of silent periods after treatment was significant for the masseter but not for the posterior temporalis muscle. A possible explanation for the observed difference would be as follows: The silent period is understood as a protective reflex to prevent the teeth from being damaged by an excessive force by inhibiting the motor output to the jaw closing muscles. Given that the upper incisors in crossbite are likely to have premature contacts more frequently than in normal incisor relationship and because incisors are very sensitive to the external force, it can be speculated that silent periods occur more frequently in the power muscle, i.e., the masseter, to reduce the strong force to be applied to the incisors, than in the jaw displacement muscle, i.e., the posterior temporalis muscle.

The current results suggest that children with incisor crossbite could chew foods efficiently with more grinding jaw movement patterns, faster jaw movement velocity in the lateral direction, and fewer incidences of silent periods of the superficial masseter muscle after the orthodontic corrections of incisor crossbite were completed. These results give a neurophysiologic rationale for explaining the significance of orthodontic treatment in improving lowered masticatory efficiency in a way that the change in direction of the occlusal load achieved by tooth movements influences the periodontal sensory input, which in turn modifies the trigeminal motor output and thus, eventually, jaw muscle activities. In addition, it should be emphasized that the jaw movements and the occurrence of silent periods observed in the pretreatment and posttreatment stages are adaptational physiologic but not pathologic responses of the neural system to the existing peripheral structures. This is regardless of whether they show "good" occlusion or "mal" occlusions that occasionally give a direction of occlusal loading opposite to that determined for "good" occlusion. Consequently, the terms *malfunction* and *dysfunction* should be used cautiously.

CONCLUSIONS

The posttreatment records of 10 children with incisor crossbite showed broader masticatory jaw movement patterns in the frontal view and faster jaw movement velocity in the lateral direction at a level close to the habitual maximum intercuspation position, when compared with the pretreatment records. The duration of the muscle activity and the incidence of the silent period in the superficial masseter muscle decreased after the correction of the incisor crossbite.

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