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Citation

Issue Date
2015-09-08

URL
http://hdl.handle.net/10232/25401
http://ir.kagoshima-u.ac.jp
First molar cross-bite is more closely associated with a reverse chewing cycle than anterior or pre-molar cross-bite during mastication

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SUMMARY A posterior cross-bite is defined as an abnormal bucco-lingual relationship between opposing molars, pre-molars or both in centric occlusion. Although it has been reported that patients with unilateral posterior cross-bite often show unique chewing patterns, the relationship between the form of cross-bite and masticatory jaw movement remains unclear in adult patients. The objective of this study was to investigate masticatory jaw movement among different forms of cross-bite. One hundred and one adults were recruited in this study: 27 had unilateral first molar cross-bite (MC group); 28, unilateral pre-molar cross-bite (PC group); 23, anterior cross-bite (AC group); and 23, normal occlusion (control group). Masticatory jaw movement of the lower incisor point was recorded with six degrees of freedom jaw-tracking system during unilateral mastication. Our results showed that the reverse chewing ratio during deliberate unilateral mastication was significantly larger in the MC group than in the PA (P < 0.001), AC (P < 0.001) and control (P < 0.001) groups. These findings suggest that compared to the anterior or pre-molar cross-bite, the first molar cross-bite is more closely associated with a higher prevalence of a reverse chewing cycle.

KEYWORDS: first molar, cross-bite, jaw movement, chewing pattern, malocclusion, mastication

Accepted for publication 30 July 2014
the functional significance of the first molar, the prevalence of first molar cross-bite may influence masticatory function more strongly than that of the pre-molar and anterior teeth would. However, it is not clear how differences in the form of cross-bite are associated with the chewing pattern during unilateral mastication in adult patients.

Therefore, the aim of this study was to investigate the masticatory jaw movement in adult patients with different forms of cross-bite. Our null hypothesis was that no difference existed between first molar cross-bite and any other classification of cross-bite in determining masticatory jaw movement.

**Subjects and methods**

**Subjects**

Seventy-eight patients (mean age, 24.5 years; 20 men and 58 women) with unilateral anterior and/or posterior cross-bite were selected from 2138 consecutive patients who visited the orthodontic clinic at Kagoshima University Hospital from 2005 to 2012. Twenty-three control subjects (mean age, 22.6 years; 6 men and 17 women) with strictly normal occlusion and normal dentofacial morphology and no clinical signs or symptoms of temporomandibular disorders (TMD) were selected. All patients and control subjects provided their written informed consent after receiving an explanation of the study goals and structure, which were independently reviewed and approved by the Ethics Committee at our hospital (#25-116). The study was conducted in full accordance with ethical principles, including those of the World Medical Association Declaration of Helsinki.

We examined their clinical information, including data obtained from dental casts, frontal and lateral cephalograms, and clinical signs and symptoms of TMD [temporomandibular joint (TMJ) sounds, tiredness/stiffness, pain, difficulties opening their mouth widely and TMJ locking or impaired opening] by clinical examinations and questionnaires based on the Research Diagnostic Criteria for TMD Axis I (14). In addition, we recorded the functional mandibular lateral shift during jaw opening and closing movements using six degrees of freedom jaw-tracking system (7, 15–17), which is later described in detail. The functional mandibular lateral shift represents the difference in lateral shift of the mandible from maximal opening to maximal intercuspation.

Figure 1 shows a flow chart of the selected patients who met the exclusion and inclusion criteria; they were divided into three groups according to the region of their cross-bite: 27 in the molar cross-bite group (MC group; mean age, 25.8 years; 7 men and 20 women), 28 in the pre-molar cross-bite group (PC group; mean age, 24.8 years; 7 men and 21 women) and 23 in the anterior cross-bite group (AC group; mean age, 22.7 years; 6 men and 17 women). Edge-to-edge or negative overbite teeth were not included as cross-bite teeth. For the MC and PC groups, the presence of an anterior cross-bite was not an exclusion criterion (five patients in the MC group had an anterior cross-bite, and six patients in the PC group had an anterior cross-bite), because previous reports had indicated that an anterior cross-bite would have little of an influence on the interest parameter of this study (i.e. reverse chewing cycles and a negative closing angle) (6, 18).

No significant differences were noted in the mean age, female/male ratio or skeletal pattern in the lateral views among the three unilateral cross-bite patient groups and the control group. In the frontal view, skeletal patterns in the MC and PC groups were observed as a midline shift towards the cross-bite side, although no difference in the skeletal patterns was observed between the control and AC groups. The magnitude of mandibular asymmetry was indicated by measuring the distance from the midline axis to the Menton, which were 4.1 ± 3.7 mm in the MC group and 3.2 ± 3.4 mm in the PC group. The mean functional mandibular lateral shift was small in all the groups, as expected in subjects without TMD (MC group: 1.9 ± 1.6 mm; PC group: 2.1 ± 1.3 mm; AC group: 1.9 ± 1.5 mm; control group: 1.4 ± 1.1 mm).

**Jaw movement-recording system**

To record masticatory mandibular movement, six degrees of freedom jaw-tracking system was used (7, 15–17). The system consisted of a head frame, face bow, pointer, light-emitting diodes (LEDs), CCD cameras, amplifier and personal computer (Gnathohexagraph system version 1.31*). The head frame and face

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*OnoSocki Ltd., Kanagawa, Japan.
bow, each with three LEDs, were attached securely to the head and to a dental clutch that was bonded to the labial surfaces of the lower incisors, respectively. A stand with two vertically installed CCD cameras, with an intercamera distance of 1.0 m, was placed in front of the participant. The horizontal distance between the cameras and the head of each participant was maintained at approximately 1.2 m during the recording. Using a pointer with two LEDs, the lower central incisor point was recorded on the right and left sides. The sampling frequency of the mandibular movement was 89.3 Hz. The mean measurement error of this jaw-tracking system was 150 μm (s.d., 10) (19).

Test foodstuff

Standard 5-g gummy jelly† (7, 15–17) was specially prepared for this study. The shape of the gummy jelly was similar to that of a truncated cone (5-g gummy jelly: height, 11 mm; top diameter, 12 mm; base diameter, 22 mm). The truncated cone shape was chosen because of its high stability, which ensured that a consistent height could be maintained when positioning the food on the occlusal surface and during chewing. Other relevant characteristics of the food used in this study were as follows: colour (yellow), taste (orange), hardness (30.5 kg), cohesiveness (0.89 TU) and strain (21.9 TU). The mechanical characteristics of the test gummy jelly were measured using a texturometer (GTX-2‡), as previously described (15).

Experimental procedure

Each participant was seated on a chair in an upright but comfortable position with their head naturally oriented. During recording, they were asked to fixate on a red point on the CCD camera. The test food was placed on the tongue of each subject, and maximum intercuspation of the teeth was performed; this position was recorded as the centric occlusion (CO). Three chewing sessions were performed by each subject: (i) a training session in which the subject chewed freely under experimental conditions and (ii) deliberate unilateral mastication of the gummy jelly on the cross-bite side and non-cross-bite side, respectively.

Data analysis

For the analysis of deliberate unilateral mastication on the cross-bite side, 10 representative cycles were selected using original software§. Because the

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*Fig. 1. Flow chart illustrating the patient enrolment.*

†Meiji Seika Kaisha Confectionery R&D Labs, Saitama, Japan.
‡Zenken Company Ltd., Tokyo, Japan.
§University of Kagoshima, Kagoshima, Japan.
properties of the test food change throughout mastication, jaw movement was analysed to assess chewing cycles performed during the initial stages of mastication. The data from the first cycle were not used in the analysis because the subjects usually used this cycle to place the sample between their teeth and to gather information about the food being chewed. Other exclusion criteria for the cycle included at least one of the following characteristics: (i) maximum opening <5-0 mm, (ii) minimum closing >2-0 mm or (iii) cycle duration <300 ms. Cycle duration, maximum closing velocity, vertical amplitude and cycle axis were calculated the average of 10 chewing cycles (16, 17). The closing angle and cycle width were determined at the vertical slice level, 2-0 mm below the maximum intercuspal position in the frontal view (16). Also, the chewing cycles were divided into non-reverse or reverse chewing cycle, based on a negative or positive closing angle (reverse chewing ratio) (4, 6). A schematic of the chewing cycle in the frontal view and the masticatory jaw movement parameters is shown in Fig. 2.

Statistical analysis

In a priori power analyses, we performed a sample size calculation (20) using data derived from a pilot study, with five unilateral cross-bite patients in each group and five subjects in a control group. Based on the parameters of interest (the reverse chewing ratio), the effect size f was estimated. Assuming a significance level of 0.05 and a power of 90%, with an effect size f of 0.46 for intergroup comparisons, the sample size calculation indicated that 18 subjects were required in each group.

For each of the jaw movements, one-way analysis of variance models (ANOVA) and Bonferroni multiple comparison tests for post hoc comparisons were used to determine the significance of the differences among the four groups. A P value <0.05 was considered statistically significant. Statistical analyses were performed with SPSS version 20 for Windows (SPSS for Windows).

Results

Table 1 shows the means and statistical significances of the jaw movement variables in the three cross-bite groups and the control group (Fig. 3). Intergroup comparisons showed that the closing angle in deliberate unilateral mastication was significantly smaller in the MC group than in the PA (P<0.001), AC (P<0.001) and control (P<0.001) groups, and the reverse chewing ratio was significantly larger in the MC group than in the PA (P<0.001), AC (P<0.001) and control (P<0.001) groups. The cycle axis was significantly smaller in the MC group than in the AC (P<0.05) and control groups (P<0.001), although no significant differences in this variable were observed between the MC and PC groups. Moreover, cycle width was significantly smaller in the MC group than in the control group (P<0.01), although no statistically significant differences were observed in cycle width between the MC group and the PA and AC groups. There are no significant differences in cycle duration, maximum closing velocity and vertical amplitude among four groups.

Discussion

Patients with unilateral posterior cross-bite often show unique chewing patterns (4, 5). In this study, we examined the relationship between the different
forms of cross-bite and the masticatory jaw movement in adult patients. Our results showed that first molar cross-bite is more closely associated with a reverse chewing cycle than anterior or pre-molar cross-bite during mastication.

In this study, we included only adult patients with permanent dentition and no clinical signs or symptoms of TMD. It is difficult to examine the relationship between prevalence of the cross-bite site and masticatory function in children with mixed dentition, because a few permanent teeth may still be unerupted or erupting in these children. Moreover, with regard to statistical power, sample size calculation revealed that a sample of 18 subjects in each group was sufficient to achieve a 90% statistical power. Because at least 23 subjects were included in each group, the statistical power was sufficiently high, and the results obtained are thus reliable.

The high frequency of a reverse chewing cycle (83%) on the cross-bite side in the MC group in our study was consistent with the findings of previous studies, that is the frequency of reverse chewing cycles is substantially increased in patients with unilateral posterior cross-bite (4–6). In subjects with normal

### Table 1. Intergroup comparison of jaw movement variables during unilateral mastication on the cross-bite side

<table>
<thead>
<tr>
<th>Jaw movement variables</th>
<th>MC group</th>
<th>PC group</th>
<th>AC group</th>
<th>Control group</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle duration (s)</td>
<td>0.92 0.23</td>
<td>0.89 0.22</td>
<td>0.96 0.33</td>
<td>0.87 0.24</td>
<td>N.S. N.S. N.S.</td>
</tr>
<tr>
<td>Maximum closing velocity (mm s⁻¹)</td>
<td>82.9 42.8</td>
<td>71.8 28.3</td>
<td>73.9 25.4</td>
<td>87.0 23.6</td>
<td>N.S. N.S. N.S.</td>
</tr>
<tr>
<td>Vertical amplitude (mm)</td>
<td>14.1 4.1</td>
<td>12.8 4.4</td>
<td>13.0 2.3</td>
<td>13.9 2.6</td>
<td>N.S. N.S. N.S.</td>
</tr>
<tr>
<td>Cycle axis (°)</td>
<td>0.7 8.2</td>
<td>3.7 10.6</td>
<td>6.8 12.1</td>
<td>12.1 7.5</td>
<td>*** N.S. *</td>
</tr>
<tr>
<td>Cycle width (mm)</td>
<td>0.9 0.5</td>
<td>1.5 1.5</td>
<td>1.5 1.0</td>
<td>2.4 1.6</td>
<td>** N.S. N.S.</td>
</tr>
<tr>
<td>Closing angle (°)</td>
<td>–12.9 17.3</td>
<td>16.9 19.7</td>
<td>25.5 18.2</td>
<td>34.7 12.9</td>
<td>*** *** ***</td>
</tr>
<tr>
<td>Reverse chewing ratio (%)</td>
<td>83.0 23.2</td>
<td>18.9 25.8</td>
<td>7.0 12.6</td>
<td>4.6 4.2</td>
<td>*** *** ***</td>
</tr>
</tbody>
</table>

MC indicates molar cross-bite, PC indicates pre-molar cross-bite and AC indicates anterior cross-bite.

MC group (n = 27), PC group (n = 28), AC group (n = 23) and control group (n = 23).

N.S. P > 0.05; *P < 0.05; **P < 0.01; ***P < 0.001.

Statistical test between groups: One-way analysis of variance models and Bonferroni multiple comparison tests for post hoc comparisons.

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**Fig. 3.** Mean path of the lower central incisor during chewing of test food. The dotted lines represent the path during jaw opening, whereas the solid lines represent the path during jaw closing.
occlusion, the typical chewing pattern first involved lateral deviation of the mandible towards the working side, and during closing phase, medial deviation towards the intercuspal position (ICP) (15, 17). In a reverse chewing cycle, the mandible deviates towards the ICP from the non-working side during closing phase, thus ensuring an overlap of opposing dental occlusal surfaces (4, 6). Previous studies showed that the closing path of masticatory movement reflects the individual pattern of occlusal guidance (21). In normal occlusion, the mandible closes with the buccal side of the mandibular buccal cusp tip gliding along the lingual incline of the maxillary buccal cusp and then through the ICP (22). It was found that the length of its occlusal guidance in patients with cross-bite was very short, and most patients showed point contacts (23). One possible explanation is that the high prevalence of reverse chewing cycle in patients with first molar cross-bite is considered to avoid possible interference due to bucco-lingual changes of the molar cusp, which contribute to achieve a closing masticatory path with smooth movements.

The other plausible reason for the high frequency of the reverse chewing cycle in first molar cross-bite is the suitable modulation of the direction of bite force, which may be reflected by the neuromuscular adaptations. Bite force is the compressive force that acts between a pair of opposing occlusal contact areas (13). Multiple occlusal contacts sustain loads from jaw-closing muscle contractions indirectly through food, or directly through upper and lower tooth contact (24). Therefore, broader contact areas provide better occlusal support and allow the elevator muscles to act more forcefully during chewing. The number of occlusal contacts as well as the magnitude of bite forces acting on them is greater for the molar teeth than for the pre-molar or anterior teeth (12, 13). Furthermore, the occlusal load is initially transferred in a direction perpendicular to the cuspal inclines, and the lingual inclines of the buccal cusps of the mandibular molar teeth carried the principal occlusal load in normal occlusion (25). When the broad occlusal contact points change, for example in first molar cross-bite, the primary occlusal load is transferred from the lingual inclines of the mandibular buccal cusp to the buccal inclines of the mandibular lingual cusp. These changes of the occlusal load are responsible for previous findings that apical stress was mainly directed buccally in posterior cross-bite (25). The generation of the chewing pattern is based on inputs from peripheral receptors that are directly connected to the central nervous system (26). It is considered that changes in broad occlusal contacts resulting from bucco-lingual changes of the first molar cusp on the cross-bite side send signals to the central nervous system, which, in turn, modifies the direction of masticatory force to chew forcefully with broad occlusal contacts.

Disclosure/Acknowledgments

All authors declare no potential conflict of interests with respect to the research, authorship and/or publication of this article. This study was partially supported by JSPS KAKENHI (Grant numbers 23593036, 24593105, 24390464, 24593104 and 21592617).

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