The Effects of Masticatory Movement on the Axial Inclination of the Molars after the Treatment of a Lateral Deviation of the Jaw

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Abstract

We analyzed the masticatory movement patterns of patients with skeletal Class I or III malocclusion who had lateral deviations of the jaw and were treated using orthognathic surgery. The aims of this study were (1) to compare the chewing patterns at initial examination (T1), after removal of each participant’s orthodontic appliance (T2), and after ≥ 1 year of maintenance (T3), and (2) to analyze the effects of different chewing patterns on changes in the axial inclination of the first molars. A Gnatho-Hexagraph III was used to measure the chewing patterns (with six degrees of freedom) of 21 participants (mean age: 23.2 ± 5.4 years) with a menton deviation ≥ 4 mm from the midline. A three-dimensional digital scanner was used to measure the axial inclination of the maxillary and mandibular first molars. Participants with normal chewing patterns on both the affected and unaffected sides at T1 had the same pattern at T2 and T3. In addition, 50% of the participants with reversed chewing patterns on the affected side at T1 exhibited normal patterns at T2, while 33.3% retained their original reversed pattern. Compared to the participants with normal chewing patterns, those with reversed patterns showed a significantly greater change in the inclination of maxillary and mandibular first molars on the affected side between T2 and T3. Palatal, maxillary first molar, and mandibular first molar widths showed similar results. Moreover, participants with normal chewing patterns had few changes in the buccolingual molar inclination; hence, the orientation of the molars remained unchanged.

The results showed that the axial inclination of the molars was associated with the masticatory movement pattern after orthognathic surgery, which affected molar occlusion. This study was approved by the Ethics Committee of Nihon University’s School of Dentistry at Matsudo (approval no. EC16-15-004-2)

Keywords: lateral deviation, normal chewing, crossover chewing, reversed chewing

Introduction

A lateral deviation of the mandible leads to aesthetic problems and impaired mastication because it can result in a molar crossbite. Patients with a lateral deviation of the mandible have a characteristic masticatory movement (1-3), which can be corrected using orthognathic surgery (4,5). Previous studies on participants with lateral deviations of the mandible have identified characteristic patterns of masticatory movement (e.g., reversed and crossover chewing patterns) that indicate that the masticatory movement exhibited by these individuals is asymmetric. These studies reported that the trajectory of chewing in individuals with lateral deviations of the mandible was shorter than those in individuals with normal occlusion, and often linear (1-3, 6-9). These findings clearly indicate that lateral deviations of the mandible can affect stomatognathic function (10).

Hashimoto et al. (1) examined the patterns of masticatory movement after orthognathic surgery to correct lateral deviations of the mandible and they found that the patients had a pattern similar to that of individuals with normal
occlusion. In addition, other studies showed that orthognathic surgery could result in the correction of the morphology of the mandible, thereby leading to improved function (11-13).

However, one study on the morphological changes before and after orthodontic surgery found that despite the morphological changes, the pattern of masticatory movement remained unchanged (1), and another study indicated that the pattern of masticatory movement was set at age 12-14 years and did not subsequently change (14). These findings indicate that morphological improvements do not necessarily lead to functional changes. However, few studies have carefully examined the patterns of masticatory movement and changes in the eruption of the molars.

We generated hypotheses regarding the potential changes in masticatory movement patterns among 21 patients following orthognathic surgery for lateral deviation of the jaw and during the retention period, as well as the potential contributory role of the masticatory movement patterns in the process of relapse.

We also aimed to ascertain the changes in the masticatory movement patterns and the effects of these patterns on the axial inclination of the first molars.

This study was approved by the Ethics Committee of Nihon University’s School of Dentistry at Matsudo (approval no. EC16-15-004-2).

Materials and Methods

Participants

Twenty-one participants with lateral deviations of the mandible (6 male and 15 female patients; mean age: 23.2 ± 5.4 years) were recruited.

The frontal and lateral cephalograms of each potential participant were analyzed in accordance with the Steiner analysis (Fig. 1) (15), and the inclusion criteria were as follows:

1. A menton deviation of ≥4 mm from the midline of the face (i.e., the straight line connecting the crista galli and anterior nasal spine);
2. Skeletal Class I or III malocclusion (i.e., -2° ≤ A point-nasion-B point angle [ANB] ≤ 4°).

The exclusion criteria were as follows:

1. Temporomandibular joint pain or dysfunction (e.g., trismus);
2. Previous orthodontic treatment;
3. Use of dental prostheses;
4. Dental caries or missing teeth;
5. Congenital deformity or syndrome, or previous trauma;
6. Functional cross-bite.

Measurement of masticatory movement

Measuring device: The six degrees of freedom jaw-tracking system (Gnatho-Hexagraph III, GC Corp., Tokyo, Japan)

Method: A mandibular clutch was placed on each participant’s mandibular anterior teeth. The participant was then instructed to relax in a seated position (the participant’s head was not immobilized). After the participant was positioned so that the Frankfort plane (i.e., the plane that passes through the upper margin of each ear canal and the inferior margin of the left orbit) was horizontal to the floor, a headframe and facebow were attached to the participant. The Frankfort plane was used as a reference plane to position the headframe consistently prior to measuring the masticatory movements. The following five points: the mandibular condyles, the mesiobuccal cusp of the mandibular first molars, and the point of contact between the mandibular central incisors were used in order to observe masticatory movement (16). The test food used was a piece of normal chewing gum (1.5 g 100% xylitol-containing chewing gum; Oral Care, Tokyo, Japan), which the participants were instructed to chew freely. Once the gum softened, the participants were instructed to chew the gum at the maximum intercuspal position on the affected and unaffected sides for 30 s. This masticatory movement was recorded. The pattern of masticatory movement was analyzed using the software bundled with the equipment used to measure the masticatory movement.

The assessments were as follows:

1. Masticatory movement patterns (Fig. 2).
2. Changes in the masticatory movement patterns from T1 to T2 and from T2 to T3 (Fig 3(a)).
3. Changes (%) in the masticatory movement patterns on the affected and unaffected sides (Fig 3(b)).

Measurements of dentition molds

Measuring device: 3D Dental Scanner (Yasunaga Computer Systems Co., Inc., Fukui, Japan)

Method: The items in Figs. 5 and 6 were measured using the method described by Eguchi et al. (19). Molds of the upper and lower dental arch were taken at T1, T2, and T3.
Three-dimensional (3D) data based on the molds were obtained using a 3D Dental Scanner (Yasunaga Computer Systems Co., Inc, Fukui, Japan). The data were analyzed using specialized software for analyzing 3D data (Body-Rugie, Medic).

The changes in each measurement (which are listed below) between T2 and T3 were calculated, and the chewing patterns were compared. The plane passing through the incisal ridge and the cusps of the second premolars and first molars served as the maxillary reference plane. The plane passing through the incisal ridge of the mandibular central incisors and the cusps of the mandibular second deciduous molars (second premolars) and first molars served as the mandibular reference plane. For each of the sets of measurements (i.e., the maxillary and mandibular measurements), a straight line passing through the cusps of the second premolars and the first molars served as the x-axis, and a straight line orthogonal to the x-axis served as the y-axis. A straight line orthogonal to the x- and y-axis, in the reference plane, served as the z-axis (Fig. 4).

Measurement items were decided as per the papers (20–23).

Measurement item:
1. Buccolingual inclination of the maxillary and mandibular first molars (Fig. 4);
2. Width of the maxillary dental arch (U6–6CW; Fig. 5);
3. Width of the mandibular dental arch (L6–6CW; Fig. 5);
4. Palatal width at the maxillary first molars (U6GW; Fig. 5);
5. Classification based on molar alignment (i.e., the
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Fig. 2. Classification of chewing patterns
Normal pattern: From centric occlusion (CO), the mandible moves downward and then laterally toward the chewing side or the non–chewing side before returning to CO along a concave, convex, or linear path
Reversed pattern: The reverse of normal chewing; the mandible moves laterally first before moving downward and then returning to CO
Crossover pattern: The mandible moves slightly laterally, downward, slightly laterally again, and then returns to CO

| Affected side     | Normal pattern | Crossover pattern | Reversed pattern |
|-------------------|----------------|------------------|------------------|
| (N=21)            |                |                  |                  |
| T1                | 6/6 (100%)     | 6/15 (40%)       | 9/15 (60%)       |
|                   | 1 3 6 8        | 5 14 18          |                  |
|                   | (19 2)         | (10 11 12 13)    | (16 17 18 20)    |
| T2                | 12/12 (100%)   | 13/16 (93.7%)    | 2/3 (66.6%)      |
|                   | 1 2 3 4        | 12/14/16         | 14/16            |
|                   | (6 7 8 9)      | (10 11 13 15)    | (17 18 20)       |
| T3                | 9/9 (100%)     | 15/15 (100%)     | 4/6 (66.6%)      |
|                   | 1 2 3 4        | 12/13/14/16      | 14/16            |
|                   | (6 7 8 9)      | (10 11 12 13)    | (15 17 18 20)    |

| Unaffected side   | Normal pattern | Crossover pattern | Reversed pattern |
|-------------------|----------------|------------------|------------------|
| (N=21)            |                |                  |                  |
| T1                | 13/16 (93.7%)  | 3/16 (6.3%)      | 3/5 (60%)        |
|                   | 1 2 3 4        | 12/14/16         | 14/16            |
|                   | (6 7 8 9)      | (10 11 13 15)    | (17 18 20)       |
| T2                | 2/5 (40%)      | 15/15 (100%)     | 4/6 (66.6%)      |
|                   | 1 2 3 4        | 12/13/14/16      | 14/16            |
|                   | (6 7 8 9)      | (10 11 12 13)    | (15 17 18 20)    |
| T3                | 15/15 (100%)   | 2/3 (66.6%)      | 14/16            |
|                   | 1 2 3 4        | 12/13/14/16      | 14/16            |
|                   | (6 7 8 9)      | (10 11 12 13)    | (15 17 18 20)    |

Fig. 3(a). Change (%) in the chewing pattern on the affected and unaffected sides in each patient
T1: At initial examination; T2: After removal of the orthodontic appliance; T3: After maintenance for ≥ 1 year
○ : Normal bite ← : No significant in change
● : Crossbite ◦ : Significant in change
buccolingual alignment of the first molar on the affected and unaffected sides was determined at T1 and the molars that were aligned normally were classified as being indicative of normal bites, while the molars that were unaligned were classified as being indicative of crossbite: Fig. 3(a), (b)). In Figs. 3, ○ indicates a normal bite and ● indicates a crossbite.

Assessment time points
The assessment timepoints were as follows:
- At initial examination (T1)
- After removal of the orthodontic appliance (T2)
- After maintenance for ≥ 1 year (T3)

Based on the axial inclinations of the maxillary and mandibular first molars on the affected and unaffected sides at T2 and T3, the changes in the masticatory movement pattern were calculated and compared. In addition, changes in the width of the maxillary dental arch (U6–6CW, L6–6CW, and U6GW) at T2 and T3 resulting from the same masticatory movement pattern on the affected side were calculated (Fig. 6(a), (b)).

All measurements in this study were made by the same individual. All measurements were made in duplicate, and measurement reproducibility was examined. The author re-assessed a series of 20 subjects two months after the initial measurements were taken. The values showed good reproducibility.

Statistical analysis
The changes in the masticatory movement patterns were analyzed using McNemar’s test. The differences in the axial inclination of the maxillary and mandibular first molars and width of the dentition between cases involving normal, crossover, and reversed chewing patterns were analyzed using Kruskal–Wallis and Mann–Whitney U tests.
Results

Measurements based on the frontal and lateral cephalograms

The mean menton deviation, occlusal plane angle, and ANB angle were $7.8 \pm 3.1$ mm, $2.4 \pm 1.4^\circ$, and $1.3 \pm 2.5^\circ$, respectively.

Changes in the masticatory movement patterns on the affected and unaffected sides

The changes in the masticatory movement patterns on the affected and unaffected sides are shown in Fig. 3(a),(b). There was a significant difference between T1 and T2 in the masticatory movement patterns on the affected sides ($p = 0.03$). There were no significant differences in the patterns between T1 and T2 on the unaffected sides. In addition, there was no significant difference between T1 and T2 in the pattern of masticatory-movement patterns on the affected and unaffected sides.

At T1, six (28.5%), three (14.2%), and 12 (57.1%) out of the 21 participants had normal, crossover, and reversed chewing patterns on the affected side, respectively. At T2, 12 (57.1%), three (14.2%), and five (28.5%) out of the 21 participants had normal, crossover, and reversed chewing patterns on the affected side, respectively. Lastly, at T3, 12 (57.1%), four (19.0%), and five (23.8%) out of the 21 participants had normal, crossover, and reversed chewing patterns on the affected side, respectively. Two, one, and seven of the participants with normal, crossover, and reversed chewing patterns, respectively, had crossbites.

None of the six participants with normal chewing patterns on the affected side at T1 experienced changes in their chewing patterns by T2 or T3. Two out of the three participants with crossover chewing patterns on the affected side at T1 experienced changes in their chewing patterns to crossover chewing patterns by T2, and the remaining participant did not experience a change in chewing pattern. None of the three participants with crossover chewing patterns on the affected side at T2 and T3 experienced changes in their chewing patterns. Six of the 12 participants with reversed chewing patterns on the affected side at T1 experienced changes in their chewing patterns to normal chewing patterns by T2, and four did not experience changes in their chewing patterns. Five of the six participants with reversed chewing patterns on the affected side at T2 did not experience changes in their chewing patterns by T3.

Only one participant had a chewing pattern at T2 that differed from that at T3; the participant had a reversed chewing pattern at T2 that changed to a crossover chewing pattern.

At T1, 16 (76.1%), two (9.5%), and three (14.2%) out of
the 21 participants had normal, crossover, and reversed chewing patterns on the unaffected side, respectively. At T2, 15 (71.4%), three (14.2%), and three (14.2%) out of the 21 participants had normal, crossover, and reversed chewing patterns on the unaffected side, respectively. Lastly, at T1, 17 (80.9%), two (9.5%), and two (9.5%) out of the 21 participants had normal, crossover, and reversed chewing patterns on the unaffected side, respectively.

On the unaffected side at T1, 13 out of 16 participants had normal chewing patterns, at T2 from T1 and all had normal occlusion from T2 to T3. None of the participants with crossover or reversed chewing patterns on the unaffected side at T1 experienced changes in their chewing patterns by either T2 or T3. Two out of the three participants with reversed chewing patterns on the unaffected side at T1 experienced changes in their chewing patterns to normal chewing patterns by T2, and the remaining participant did not experience a change in their chewing patterns.

Two participants had a chewing pattern at T2 that differed from that at T3. One of these participants had a reversed chewing pattern while the other had a crossover chewing pattern at T2, and both participants had normal chewing patterns at T3.

Changes in the inclination of the teeth as a result of the same masticatory movement pattern on the affected and unaffected side at T2 and T3

The changes in the inclination of the maxillary and mandibular teeth as a result of the same masticatory movement pattern on the affected side between T2 and T3 are shown in Fig. 6(a). The statistical significance of the changes in the inclination of the teeth was tested. The changes in the inclination of the teeth were significantly greater for participants with reversed chewing patterns compared to those with normal or crossover chewing patterns.
The changes in the inclination of the maxillary and mandibular teeth as a result of the same masticatory movement pattern on the unaffected side between T2 and T3 are shown in Fig. 6 (b). There were no significant differences in the inclination of the teeth between the three groups of participants with different chewing patterns.

Changes in the width of the dentition as a result of the same masticatory movement pattern on the affected side at T2 and T3

The changes in the width of the dentition as a result of the same masticatory movement pattern on the affected side at T2 and T3 are shown in Fig. 7. The participants with reversed chewing patterns had significantly greater changes in the width of their dental arch (U6–6CW, L6–6CW, and U6GW) compared to those with normal or crossover chewing patterns.

Discussion

Masticatory movement patterns

This study examined 1) Changes in the chewing patterns in the masticatory movement and retention period, 2) Changes in the patterns of masticatory movement and the effects of these patterns on the axial inclination of the molars.

In result, it became clear that the chewing movement
changes in T1 and T2. However, it became clear that it does not change between T2 and T3. And a reversed chewing pattern tended to lead to relapse.

This study classified participants on the basis of three typical chewing patterns. Approximately 80% of the participants studied by Yano et al. (3) and Proeschel (24) had one of the three masticatory movement patterns that were analyzed in this study. The masticatory movement patterns were classified as normal, reverse, or crossover chewing.

In participants with normal chewing patterns, normal alignment of the molars on the affected and unaffected sides was often observed, and the masticatory movement patterns did not change between T1, T2, and T3. Therefore, the normal chewing pattern was the most consistent of the three patterns of masticatory movement.

In a crossover chewing pattern, during masticatory movement, the mandible moves slightly laterally, downward, slightly laterally again, and then returns to centric occlusion. However, as a result of the lateral deviations of the mandible, some of the participants had crossover chewing patterns despite not having temporomandibular joint pain or dysfunction (e.g., trismus).

The results show that over 50% of the participants with reversed chewing patterns at T1 had crossbites. This supports the findings of a previous study that showed that molar crossbites can cause occlusal interference, thereby hindering masticatory movement (8). Moreover, a study of individuals with reversed chewing patterns (i.e., the mandible moves laterally and then downward) but without molar crossbites indicated that they each had a crossbite involving the anterior teeth and supernumerary teeth in the premolar region, which caused the reversed chewing pattern (8).

These findings all indicate that occlusal interference can lead to a reversed chewing pattern.

There was a significant difference between T1 and T2 in the variation of the masticatory movement pattern on the
affected sides. Among participants with reversed chewing patterns on the affected side T1, 50% had normal chewing patterns on the affected side by T2. Studies of children with crossbites have found that after their crossbites were corrected, each child had a more normal chewing pattern (i.e., the mandible moved downward and then laterally) (25,26). In addition, a study on orthognathic surgery for adults with skeletal Class III malocclusions found that the proportion of adults who had reversed chewing patterns decreased after surgery (27). After transection of the jaw to treat lateral deviations, the molars on the affected and unaffected sides are aligned, which is likely to have caused the changes observed in the masticatory movement patterns between T1 and T2. Changes in occlusal contacts alter the masticatory muscles, temporomandibular joints, and directions of masticatory forces, thereby eliminating occlusal interference and causing a change in the masticatory movement pattern.

In contrast, there was no significant difference between T2 and T3 in the variation of the masticatory movement pattern on the affected and unaffected sides. Of those who had reversed and crossover chewing patterns at T1, 33% and 100%, respectively, experienced no change in their chewing patterns by T2. This indicates that masticatory movement patterns do not necessarily change even if morphological improvement occurs after orthognathic surgery. A previous study showed that chewing was controlled by a central pattern generator (CPG) located in the pons and medulla oblongata (28). In adults, the CPG does not change once it has been established. Studies on animals have also indicated that animal chewing patterns change very little (29, 30). Thus, although surgery can cause changes in occlusal contacts between T1 and T2, the existence of the CPG may mean that these changes do not always result in changes in the masticatory movement pattern. In participants whose chewing patterns did not change, it may be that the CPG had been established prior to surgery.

Changes in the axial inclination of the maxillary and mandibular teeth

The affected side was more susceptible than the unaffected side to the effects of different masticatory movement patterns on the inclination of the teeth. In addition, reversed and crossover chewing patterns resulted in greater changes in the inclination of the maxillary and mandibular teeth compared to normal chewing patterns. After maintenance for $\geq 1$ year, the inclination of the molars changed as a result of the masticatory movement patterns. A study on masticatory movements and changes in molar inclination showed that chewing with grinding movements causes the mandibular molars to incline more buccally (31), which indicates that masticatory movement is closely related to changes in the axial inclination of the teeth. Therefore, for individuals with normal chewing patterns that involve grinding movements, the molar inclination of the teeth changes very little after orthognathic surgery.

Changes in the width of the maxillary and mandibular dental arch

The maxillary and mandibular molars did not revert back to form crossbites in any of the participants by T3. However, there were greater changes in the width of the maxillary dental arch in participants with reversed chewing patterns compared to those with normal or crossover chewing patterns, indicating that regression was more likely in those with reversed chewing patterns. Negishi et al. (31) reported that chewing with grinding movements caused the mandibular molars to incline more buccally and their width to expand. It is likely that this phenomenon affected the width of the maxillary and mandibular dental arch and the axial inclination of the teeth at T2 and T3.

Masticatory movement was classified into three patterns: normal, crossover, and reversed chewing. Fewer changes in the molar inclination and width of the maxillary and mandibular teeth were observed at T2 and T3 among the participants with normal chewing patterns compared to those with the other two chewing patterns. Therefore, the molar inclination and width of the maxillary and mandibular teeth were more consistent among the participants with normal chewing patterns compared to those with the other patterns. Reversed chewing patterns also resulted in substantial changes in the molar inclination and width of the maxillary and mandibular teeth during maintenance, and tended to lead to regression.

References

1. Hashimoto S, Sugawara J, Tomoyose Y, Mitani H: Assessment of maxillofacial morphology and the path of masticatory movement after surgery to correct skeletal mandibular prognathism and mandibular asymmetry. J Tohoku Orthodont Soc, 12: 3–12, 2004.
2. Tomoyose Y, Bandai H, Sugawara J, Mitani H: Characteristics of the path of masticatory movement in patients with skeletal mandibular prognathism and mandibular asymmetry: Relationship between craniofacial morphology, temporomandibular joint morphology, and occlusion. Orthod Waves, 61: 376–391, 2002.

3. Yano K, Kubota M, Shinohara C, Kanegae H, Shibasaki Y: The relationship between the condylar angle and habitual chewing in skeletal mandibular prognathism and jaw asymmetry. Jpn J Jaw Deformities, 102: 110–116, 2000.

4. Wang D, Fu H, Zeng R, Yang X: Changes of mandibular movement tracings after the correction of mandibular protrusion by unilateral sagittal split ramus osteotomy. J Oral Maxillofac Surg, 67: 2238–2244, 2009.

5. Wen-Ching Ko E, Huang CS, Lo LJ, Chen YR: Longitudinal observation of mandibular motion pattern in patients with skeletal class III malocclusion subsequent to orthognathic surgery. J Oral Maxillofac Surg, 70: e158-e168, 2012.

6. O’Byrn BL, Sadowsky C, Schneider B, BeGole EA: An evaluation of mandibular asymmetry in adults with unilateral posterior crossbite. Am J Orthod Dentofacial Orthop, 107: 394–400, 1995.

7. Nakaminami T, Nishio K, Miyauchi S, Maruyama T: The effect of molar cross-bite on stomatognathic function. Proceedings Jpn Soc Stomatognathic Funct, 6: 87–96, 1968.

8. Tomonari H, Ikemori T, Kubota T, Uehara S, Miyawaki S: First molar cross-bite is more closely associated with a reverse chewing cycle than anterior or pre-molar cross-bite during mastication. J Oral Rehabil, 41: 890–896, 2014.

9. Piancino MG, Talpone F, Dalmasso P, Debernardi C, Lewin, Bracco P: Reverse-sequencing chewing patterns before and after treatment of children with unilateral posterior crossbite. Eur J Orthod, 28: 480–484, 2006.

10. Sato S, Takamoto K, Goto M, Kamoi S, Suzuki Y: Discussion of the mechanism for development of a skeletal cross-bit and lateral deviation of the mandible. J Kanagawa Odontological Soc, 25-1: 93-98, 1990.

11. Nagai I, Tanaka N, Noguchi M, Suda Y, Sonoda T, Kohama G: Changes in occlusal state of patients with mandibular prognathism after orthognathic surgery: a pilot study. Br J Oral Maxillofac Surg, 39: 429–433, 2001.

12. Ohkura K, Harada K, Morishima S, Enomoto S: Changes in bite force and occlusal contact area after orthognathic surgery for correction of mandibular prognathism. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 91: 141–145, 2001.

13. IwaseM, Ohashi M, Tachihana H, Toyoshima T, Nagumo M: Bite force, occlusal contact area and masticatory efficiency before and after orthognathic surgical correction of mandibular prognathism. International Journal of Oral and Maxillofacial Surgery, Volume 35: 1102-1107, 2006.

14. Gibbs CH, Wickwire NA, Jacobson AP, Lundeen HC, Mahan PE, Lupkiewicz SM: Comparison of typical chewing patterns in normal children and adults. J Am Dent Assoc, 105: 33–42, 1982.

15. Proffit WR: Contemporary Orthodontics, Japanese translation. City: Tokyo Publisher; Tokyo in Japan. p.175–177, 2004.

16. Hayashi R, Kawamura A, Kasai K: Relationship between masticatory function, dental arch width, and bucco-lingual inclination of the first molars. Orthod Waves Jpn Ed, 65: 120–126, 2006.

17. Nie Q, Kanno Z, Xu T, Lin J, Soma K: Clinical study of frontal chewing patterns in various crossbite malocclusions. Am J Orthod Dentofacial Orthop, 138: 323–329, 2010.

18. Shiga H, Kobayashi Y, Arakawa I, Yokoyama M, Tanaka A: Relationship between pattern of masticatory path and state of lateral occlusal contact. J Oral Rehabil, 36: 250–256, 2009.

19. Eguchi S, Townsend GC, Hughes T, Kasai K: Genetic and environmental contributions to variation in the inclination of human mandibular molar. Orthod Waves, 63: 95–100, 2004.

20. Oliveira NL, Da Silveira AC, Kusnoto B, Viana G: Three-dimensional assessment of the maxilla: A comparison of 2 kinds of palatal expanders. Am J Orthod Dentofacial Orthop, 126: 354–362, 2004.

21. Veli I, Yulisel B, Uysal T: Longitudinal evaluation of dental arch asymmetry in Class II subdivision malocclusion with 3-dimensional digital models. Am J Orthod Dentofacial Orthop, 143: 763–770, 2014.

22. Okano M: Bucco-lingual inclination of the first molar and expansion of the arch width: A comparison of Japanese and 2 South Pacific populations. Orthod Waves Jpn Ed, 65: 112–121, 2006.

23. Langberg BJ, Araik M, Miner RM: Transverse skeletal and dental asymmetry in adults with unilateral posterior crossbite. Am J Orthod Dentofacial Orthop, 127: 6–16, 2005.

24. Proeschel PA: Chewing patterns in subjects with normal occlusion and with malocclusions. Semin Orthod, 12: 2–138–149, 2006.

25. Throckmorton GS, Buschang PH, Hayasaki H, Pinto AS: Changes in the masticatory cycle following treatment of posterior unilateral crossbite in children. Am J Orthod Dentofacial Orthop, 120: 521–529, 2001.

26. Piancinoa MG, Falla D, Merlo A, Valvelonga T, de Biase C, Dalessandri D, Debernardi C: Effects of therapy on masseter activity and chewing kinematics in patients with unilateral posterior crossbite. Arch Oral Biol, 67: 61–67, 2016.

27. Piancino MG, Frongia G, Dalessandri D, Bracco P, Ramieri G: Reverse cycle chewing before and after orthodontic-surgical correction in class III patients. Oral Surg Oral Med Oral Pathol Oral Radiol, 115: 328–331, 2013.

28. Lund JP, Kolta A: Generation of the central masticatory pattern and its modification by sensory feedback. Dysphagia, 21: 167–174, 2006.
29. Byrd KE, Luschei ES: Cerebellar ablation and mastication in the guinea pig (Cavia porcellus). Brain Res, 197: 577–581, 1980.

30. Huang X, Zhang G, Herring SW: Alterations of muscle activities and jaw movements after blocking individual jaw-closing muscles in the miniature pig. Arch Oral Biol, 38: 291–297, 1993.

31. Negishi S, Hayashi R, Saitoh K, Kasai K: Effects of masticatory exercises with hard chewing gum on chewing patterns and eruption of the first molar in children mixed dentition. J Japan Orthodont Soc, 69: 156–162, 2010.