Influence of Simulated Loss of Posterior Occlusal Support on Three-dimensional Condylar Displacement

Ryo Sakai and Shuichiro Yamashita

*Department of Removable Partial Prosthodontics, Tokyo Dental College,
2-9-18 Kanda-Misakicho, Chiyoda-ku, Tokyo 101-0061, Japan*

Received 31 October, 2020/Accepted for publication 15 January, 2021
Published Online in J-STAGE 15 August, 2021

Abstract

The objective of this study was to verify whether loss of posterior occlusal support induced displacement of the mandibular condyles from a physiological point of view. Stabilization-type splints were fabricated for 12 healthy dentulous individuals. Each splint was designed to cover the bilateral maxillary teeth up to the second molars. To reproduce loss of posterior occlusal support, the extent of the splint was reduced one tooth at a time, bilaterally, starting from the back and moving forward sequentially. Tapping movement and lateral excursions were performed with each splint and a jaw movement tracking device with 6-degrees of freedom used to observe condylar displacement. Evaluation of 3-dimensional (3-D) displacement of the kinematic axis of the condyle during experimental jaw movement was performed under each occlusal condition with occlusal contact on all teeth, including the maxillary second molars. The habitual closing position was used as the reference. An increase was observed in 3-D displacement of the kinematic axis at the terminal point of the tapping movement with loss of occlusal support, and significant differences were observed in both condyles. An increase was also observed in 3-D displacement of the kinematic axis on the working side during lateral excursion with loss of occlusal support, and a statistically significant difference was observed in the left condyle. A small increase was observed in 3-D displacement of the kinematic axis on the non-working side during lateral excursion with loss of occlusal support. The results of this study suggest that loss of posterior occlusal support induces displacement of the mandibular condyles, suggesting that occlusal support in the molar region is an important factor in stabilization of the condylar position.

Key words: Occlusal support — Jaw movement — Kinematic axis —
Jaw movement tracking device with 6-degrees — Mandibular condyle

Introduction

In Japan, the desirability of applying a prosthesis to compensate for missing teeth and restore oral function is widely accepted. This approach is driven by the need to prevent the potential development of tooth loss-induced disorders of the stomatognathic system. On the other hand, overseas in the 1980's, Kyser¹⁰⁾ proposed shortening the dental arch to compensate for loss of occlusal support in the molar region. This approach was based on the idea that if the dentition had at least 4 occlusal units, there would be no loss of alveolar bone or stomatognathic function, even if the missing teeth were not restored. Studies on the advantages and disadvantages of a shortened dental arch have suggested that an asymmetric, shortened dental arch with premolar occlusal support and 3 or 4 occlusal units is associated with masticatory dysfunction¹⁴⁾, changes in the path of masticatory movement⁸⁾, and increased displacement of the remaining teeth⁴⁾. There has long been an ongoing discussion on the concept of shortened dental arches. Studies on this topic have been released around the world, some of which have revealed that a shortened dental arch is an effective treatment option in terms of mastication and patient satisfaction¹⁾, and that it is not a major risk factor for temporomandibular joint pain compared to molar replacement with removable partial dentures³⁾. In addition, follow-up evaluations have indicated that oral health-related quality of life and the ability to masticate was similar among patients treated for missing distal extensions, those with shortened dental arches, and those requiring prosthetic treatment. Therefore, the shortened dental arch approach is now receiving more clinical recognition in Japan as an effective method of treatment^{5,6)}. Many of these reports, however, are based on epidemiological studies, and very few have investigated this issue from a physiological point of view. Therefore, it is difficult to claim that there is experimental support for this approach. Few studies to date have analyzed the influence of condylar

movement, and the relationship between condylar position and shortening of the dental arch due to loss of posterior occlusal support remains to be investigated. Conducting a detailed analysis of this relationship would be useful in identifying potential problems surrounding shortening of the dental arch. The objective of this study was to verify the hypothesis that loss of posterior occlusal support induces displacement of the mandibular condyles.

Materials and Methods

1. Participants

The study participants comprised 12 healthy dentulous adults (9 men, 3 women; average age, 27 years, range 24–28 years; all were dentists working at this institution). The inclusion criteria were as follows: good general health; intact bilateral occlusal contacts; Angle Class I dentition confirmed by clinical examination; and no prosthesis, fixed or removable. The exclusion criteria were as follows: a history of orthodontic treatment; a history of temporomandibular disorder treatment; moderate to severe periodontal disease; and missing teeth other than a third molar. Written informed consent was received from each participant prior to commencement of the study. The study was approved by the Ethics Review Committee of Tokyo Dental College, Japan (Approval number: 729).

2. Experimental splint

Stabilization-type splints were fabricated with auto-polymerizing resin (Fit Resin, Shofu Inc., Kyoto, Japan). Each splint was designed to cover the bilateral maxillary second molars to reproduce loss of posterior occlusal support. The thickness of splint was set so that the distance between the cusp tips of the maxillary and mandibular first molars was 1 mm. Only the ball clasp between the canine and first premolar (0.8-mm ball clasp, TOMY INTERNATIONAL Inc., Tokyo, Japan) acted as a retentive force. The extent of the splint was reduced one tooth at a time, bilaterally,

Three-dimensional Condylar Displacement

Fig. 1 Experiment splints

Occlusal support was changed by sequentially reducing extent of splint from posterior to anterior under 5 occlusal conditions (splints 7 to 3).

starting from the back and moving forward sequentially. Accordingly, occlusion was set up under the following 5 conditions (Fig. 1): Splint 7, with occlusal contact including the maxillary second molars; Splint 6, with occlusal contact up to the maxillary first molars; Splint 5, with occlusal contact up to the maxillary second premolars; Splint 4, with occlusal contact up to the maxillary first premolars; and Splint 3, with occlusal contact up to the maxillary canines. During tapping movement or lateral excursion on the splint (see below), the same occlusal contact pattern as that of the subject's natural dentition was applied to the splint. Minor adjustments were made to the splints during trial insertion to make sure the participant felt no discomfort.

3. Measuring devices

A jaw movement tracking device with 6-degrees of freedom (MM-J2, Shofu Inc., Kyoto, Japan) was used to observe condylar displacement (Fig. 2). With this device, light emission from a light emitting diode attached to the face bow on the maxillary and mandibular jaw is received by a position sensitive detector sensor, and mandibular movement is calculated as relative motion of the mandible to the maxilla. The X-axis represents the anterior-posterior direction, the Y-axis the

Fig. 2 Jaw movement tracking device with 6 degrees of freedom

horizontal direction, and the Z-axis the vertical direction. At the time of measurement, a clutch created using auto-polymerizing resin was fitted to the labial surface of the maxillary and mandibular teeth of the participant using a rapid cure adhesive agent (Aron Alpha, Toagosei Co., Ltd., Tokyo, Japan). The labial surface of the splint was partially trimmed to accommodate the clutch. The reference plane was the maxillary occlusal plane (maxillary incisal point and maxillary left and right first molar distobuccal cusps). The sampling frequency was set to 200 Hz. Special software was used to determine the

Fig. 3 Flow chart of experiment

First, splint was inserted and mandible kept in physiologic rest position (A: 2 minutes). Next, 2 different jaw movements and condylar displacement were recorded with splint in place. Splint was then removed (B: 15 minutes). Splint was cut off at most posterior tooth bilaterally (C: 2 minutes). This process was performed sequentially from splint 7 to splint 3.

kinematic axis of the bilateral mandibular condyles and mandibular movement.

4. Experimental jaw movements

Measurements were performed with the participant in a sitting posture, with the head position set with a headrest so that the Frankfurt plane was parallel to the floor. The participants were required to perform 2 experimental jaw movements: a tapping motion movement; and lateral excursion. These movements were performed with and without the splint. Tapping movement was performed using visual feedback synchronized to a metronome (90 beats/min). In reference to the experimental protocol utilized by Ueno *et al.*¹⁶⁾, the participants were instructed to open the mouth approximately 2 to 4 mm wider than in the habitual closing position and repeat the tapping movement 15 times with minimal force and at a constant speed with each splint. It is difficult to perform lateral excursion between the canines when wearing a splint. Therefore, right and left lateral excursion was performed to the maximum limit on a cue provided by the operator a total of 5 times with each splint. No speed was specified. All measurements were made continuously on the same day. A flow chart of the

experiment is shown in Fig. 3. First, the splint was inserted with the mandible in the physiologic rest position (A: 2 minutes). Next, two different jaw movements and condylar displacement were recorded with the splint in place, after which it was removed (B: 15 minutes). Finally, the extent of the splint was bilaterally reduced to the most posterior tooth (C: 2 minutes). This process was performed sequentially from splint 7 to splint 3.

5. Evaluation

Condylar position at the terminal point of the tapping movement during the final 10 out of 15 tapping movements was measured with each splint. Next, the difference in condylar position between that in the habitual closing position and that after placement of splint 7 was calculated and movement in the antero-posterior, horizontal, and vertical directions measured to determine the amount of 3-dimensional (3-D) displacement on the working and non-working sides. The condylar position on the working and non-working sides during 5 repetitions of 5-mm lateral excursions was measured with each splint.

Amount of displacement is expressed as an absolute value, and all the data are tabulated as the median value.

6. Statistical analysis

The Quade test was used to analyze the effects of difference in occlusal support with respect to displacement of the kinematic axis at the terminal point of the tapping movement and during lateral excursion on the working and non-working sides. The Steel-Dwass method was used for multiple comparisons. The level of significance was established at 5% for both test methods (Statcel 4; OMS Inc., Saitama, Japan).

Results

The 3-D distribution range of the kinematic axis in the habitual closing position was compared with that before and after placement of splint 7. The kinematic axes of the bilateral mandibular condyles were displaced in the anterior direction; the amount of displacement was 0.9 mm on the right side and 1.5 mm on the left.

Displacement of the kinematic axis at the terminal point of the tapping movement with sequential loss of posterior occlusal support due to the splint is shown in Fig. 4. As posterior occlusal support was lost, 3-D displacement of the kinematic axis showed a tendency to increase bilaterally, and significant differences were observed. Multiple comparison revealed a significant difference in displacement between splint 7 and 4, and splint 7 and 3 on both sides (Fig. 4a). In addition, when 3-D displacement was separated into 3 directions (anteroposterior, horizontal, and vertical), a significant difference was observed between displacement in the horizontal direction on both sides, and vertical direction on the right side. Multiple comparison revealed a significant difference between splint 7 and 4, and splint 7 and 3 in displacement in the vertical direction on the right side (Fig. 4b, c). The trajectories of splints 7 and 3 on the kinematic axis of the bilateral condyles during tapping are shown in a representative participant in Fig. 4d, e.

Figures 5 and 6 show the amount of displacement of the kinematic axis on the work-

ing and non-working sides during lateral excursion with sequential loss of posterior occlusal support. A tendency toward an increase was observed in 3-D displacement of the kinematic axis on the working side with loss of occlusal support, and a statistically significant difference was observed in displacement on the left side (Fig. 5a). In addition, when 3-D displacement was separated into 3 directions, a significant difference was observed in the amount of vertical displacement on both sides (Fig. 5b, c). The trajectories of splints 7 and 3 on the kinematic axes of the bilateral condyles on the working side during lateral excursion are shown for a representative participant in Fig. 5d, e.

A tendency toward an increase was observed in 3-D displacement of the kinematic axis on the non-working side with loss of occlusal support. In addition, when 3-D displacement was separated into 3 directions, a significant difference was observed in the amount of displacement in the anteroposterior direction on the right side (Fig. 6b). The trajectories of splints 7 and 3 on the kinematic axes of the bilateral condyles on the non-working side during lateral excursion are shown for a representative participant in Fig. 6d, e.

Discussion

Various methods have been used to experimentally reproduce dentition with loss of posterior occlusal support. Kozawa *et al.*¹³⁾ used a unique method where full cast crowns which were temporarily bonded to molars were sequentially removed from the posterior end. Kirihaara *et al.*¹¹⁾ used a stabilization-type splint to decrease posterior occlusal support by sequentially cutting off the posterior teeth. When using this method, it was predicted that displacement of the kinematic axis during experimental jaw movements would be affected due to an increase in the vertical dimension. Nevertheless, they stated that it was possible to observe condylar displacement, even with the splint in place. Therefore, a stabilization-type splint was also used in the

Fig. 4 Influence of experimental loss of posterior occlusal support on kinematic axis during tapping movement

(a) 3-D displacement of kinematic axis at terminal point of tapping movement. (Right condylar point and Left condylar point)

(b) When 3-D displacement of kinematic axis at terminal point of tapping movement was separated into 3 directions. (Right condyle)

(c) When 3-D displacement of kinematic axis at terminal point of tapping movement was separated into 3 directions. (Left condyle)

(d) Trajectories of splints 7 and 3 on kinematic axis of right condyle during tapping movement in representative participant.

(e) Trajectories of splints 7 and 3 on kinematic axis of left condyle during tapping movement in representative participant.

Fig. 5 Influence of experimental loss of posterior occlusal support on kinematic axis on working side during lateral excursion

- (a) 3-D displacement during 5-mm lateral excursion of kinematic axis on working side. (Right condylar point and Left condylar point)
- (b) When 3-D displacement of kinematic axis during 5-mm lateral excursion of kinematic axis on working side was separated into 3 directions. (Right condyle)
- (c) When 3-D displacement of kinematic axis during 5-mm lateral excursion of kinematic axis on working side was separated into 3 directions. (Left condyle)
- (d) Trajectories of splints 7 and 3 on kinematic axis of right condyle on working side during lateral excursion in representative participant.
- (e) Trajectories of splints 7 and 3 on kinematic axis of left condyle on working side during lateral excursion in representative participant.

Fig. 6 Influence of experimental loss of posterior occlusal support on kinematic axis on non-working side during lateral excursion

- (a) 3-D displacement during 5-mm lateral excursion of kinematic axis on non-working side. (Right condylar point and Left condylar point)
- (b) When 3-D displacement of kinematic axis during 5-mm lateral excursion of kinematic axis on non-working side was separated into 3 directions. (Right condyle)
- (c) When 3-D displacement of kinematic axis during 5-mm lateral excursion of kinematic axis on non-working side was separated into 3 directions. (Left condyle)
- (d) Trajectories of splints 7 and 3 on kinematic axis of right condyle on non-working side during lateral excursion in representative participant.
- (e) Trajectories of splints 7 and 3 on kinematic axis of left condyle on non-working side during lateral excursion in representative participants.

present study. Measurements were commenced with splint 7, as this represents the reference jaw position before loss of posterior occlusal support. In addition, a single splint, rather than multiple splints, was sequentially cut and used to perform measurements so that comparisons could be made with values obtained in the reference jaw position.

A jaw movement tracking device with 6-degrees of freedom was used to investigate the influence of loss of occlusal support on condylar displacement. Hashii *et al.*⁽⁸⁾ reported that it is possible to observe condylar movement during complicated masticatory movement using this device. Moreover, since the measurement accuracy of this device is 150 μm , it is possible to observe condylar movement on the working side, which involves very small movements. The face bows weighed 30 g for the maxilla and 35 g for the mandible, minimizing change to the oral cavity.

Ishii *et al.*⁽⁹⁾ reported that when the head was tilted further back compared with in the normal sitting position, the tapping point shifted posteriorly, whereas with the head tilted more forward, it shifted more anteriorly. Therefore, in the present study, the participants were required to assume a sitting position, with the head positioned such that the Frankfort plane was parallel to the floor, thus allowing the influence of posture on mandibular position to be minimized. The kinematic axis is located at the center of jaw movement in the sagittal plane⁽¹²⁾. Therefore, it was possible to compare condylar position under different occlusal conditions by setting the measurement point on the kinematic axis. In addition, irregular movement of the temporomandibular joint was minimized by allowing the participants to move the jaw freely without forced guidance during lateral excursion.

Kirihara *et al.*⁽¹¹⁾ investigated condylar displacement with loss of bilateral molar support. Their results showed that displacement of the mandibular condyles increased as occlusal support was lost, and that displacement exceeded 1 mm when occlusal support was lost in the first premolars. A similar trend was observed in the present study, where 3-D

displacement of the kinematic axis showed a bilateral increase with loss of posterior occlusal support. When 3-D displacement amount was separated into 3 directions, a statistically significant difference was observed in the amount of displacement bilaterally in the horizontal direction and on the right side in the vertical direction. Seedorf *et al.*⁽¹⁵⁾ investigated condylar displacement during clenching when occlusal support was lost unilaterally from the posterior end. Their results showed that condylar displacement increased in the vertical direction on the side where molar support was lost, and a statistically significant difference was observed between different degrees of occlusal support. It is difficult to compare the present results with those of this earlier study as the criteria were different. However, occlusal contact in the habitual closing position would become unstable with increase in loss of occlusal support, which would affect the masticatory muscles and temporomandibular joint. This would result in stability in the horizontal and vertical directions being lost during tapping movements.

The present results showed an increase in 3-D displacement of the kinematic axis on the working side and a statistically significant difference on the left side with loss of posterior occlusal support. Moreover, when 3-D displacement was separated into 3 directions, a significant difference was observed on both sides in the vertical direction. Goldenberg *et al.*⁽⁷⁾ investigated immediate lateral shift in 4 groups with different degrees of occlusal support and reported that there was no statistically significant difference between them. In the present study, unstable occlusal support affected the occlusal relationship between the maxilla and the mandible and vertical stability could not be maintained during lateral excursion with loss of occlusal support.

The results also showed a bilateral increase in 3-D displacement of the kinematic axis on the non-working side with loss of posterior occlusal support. When 3-D displacement was separated into 3 directions, a statistically significant difference was observed on the right side in the anteroposterior direction. Cimić *et*

*al.*²⁾ investigated bilateral immediate mandibular lateral translation of different Angle types and reported that there was no statistically significant difference between them. In their report, it was suggested that the condyle on the non-working side has a larger range of motion compared to the condyle on the working side, and that it was less likely to be affected by the occlusal relationship during lateral excursion. In the present study, although stability of the condyle on the non-working side could not be maintained during lateral excursion in the anteroposterior direction, it was presumed that the condyle was less likely to be affected by loss of occlusal support.

The present study had some limitations. The number of participants was small, and an increase in the sample size might yield different the results. There was also some bias in age. The morphology of the mandibular condyle may be altered in elderly individuals, which may affect the displacement of the condyle during various mandibular movements. Moreover, the study period was short. Increasing the time of the experiment, however, might have resulted in irreversible damage to the temporomandibular joint. These are issues for future consideration.

Conclusions

This study investigated the relationship between loss of posterior occlusal support and condylar displacement. The results showed that loss of posterior occlusal support induced an increase in 3-D displacement of the condylar kinematic axis during tapping movement. In particular, stability was lost in the horizontal and vertical directions. Three-dimensional displacement of the condylar kinematic axis on the working side during lateral excursion showed a tendency to increase slightly on the left side with loss of posterior occlusal support. In particular, stability was lost in the horizontal and vertical directions. Three-dimensional displacement of the condylar kinematic axis on the non-working side during lateral excursion showed

a tendency to increase slightly on both sides with loss of posterior occlusal support. From the above, this study confirmed that loss of posterior occlusal support induced displacement of the mandibular condyles during mandibular movement. The present results also suggest that occlusal support in the molar region is an important factor in stabilization of the condylar position.

References

- 1) Aras K, Hasanreisoglu U, Shinogaya T (2009) Masticatory performance, maximum occlusal force, and occlusal contact area in patients with bilaterally missing molars and distal extension removable partial dentures. *Int J Prosthodont* 22:204–209.
- 2) Cimić S, Simunković SK, Catić A (2016) The relationship between Angle type of occlusion and recorded Bennett angle values. *J Prosthet Dent* 115:729–735.
- 3) Reissmann DR, Heydecke G, Schierz O, Marré B, Wolfart S, Strub JR, Stark H, Pospiech P, Mundt T, Hannak W, Hartmann S, Wöstmann B, Luthardt RG, Böning KW, Kern M, Walter MH (2014) The randomized shortened dental arch study: temporomandibular disorder pain. *Clin Oral Investig* 18:2159–2169.
- 4) De Oliveira BF, Seraidarian PI, de Oliveira SG, Landre J Jr, Pithon MM, Oliveira DD (2014) Tooth displacement in shortened dental arches: a three-dimensional finite element study. *J Prosthet Dent* 111:460–465.
- 5) Fueki K, Igarashi Y, Maeda Y, Baba K, Koyano K, Akagawa Y, Sasaki K, Kuboki T, Kasugai S, Garrett NR (2011) Factors related to prosthetic restoration in patients with shortened dental arches: a multicentre study. *J Oral Rehabil* 38:525–532.
- 6) Fueki K, Igarashi Y, Maeda Y, Baba K, Koyano K, Sasaki K, Akagawa Y, Kuboki T, Kasugai S, Garrett NR (2015) Effect of prosthetic restoration on oral health-related quality of life in patients with shortened dental arches: a multicentre study. *J Oral Rehabil* 42:701–708.
- 7) Goldenberg BS, Hart JK, Sakumura JS (1990) The loss of occlusion and its effect on mandibular immediate side shift. *J Prosthet Dent* 63:163–166.
- 8) Hashii K, Tomida M, Yamashita S (2009) Influence of changing the chewing region on mandibular movement. *Aust Dent J* 54:38–44.
- 9) Ishii M, Koide K, Ueki M, Asanuma N (2007)

- Influence of body and head posture on deviation of the incisal point undergoing dental treatment. *Prosthodont Res Pract* 6:217–224.
- 10) Kyser AF (1981) Shortened dental arches and oral function. *J Oral Rehabil* 8:457–462.
 - 11) Kiriara T, Yamashita S, Igarashi Y (2005) Mandibular displacement related to simulated loss of posterior occlusal support. *Eur J Prosthodont Restor Dent* 13:170–176.
 - 12) Kohno S, Ishiwara T (1971) Analysis of movement of mandibular condyle in sagittal plane. *Bull Tokyo Med Dent Univ* 18:233–245.
 - 13) Kozawa T, Igarashi Y, Yamashita S (2003) Posterior occlusal support and bite force influence on the mandibular position. *Eur J Prosthodont Restor Dent* 11:33–40.
 - 14) Sarita PT, Kreulen CM, Witter DJ, van't Hof M, Creugers NH (2003) A study on occlusal stability in shortened dental arches. *Int J Prosthodont* 16:375–380.
 - 15) Seedorf H, Seetzen F, Scholz A, Sadat-Khonsari MR, Kirsch I, Jde HD (2004) Impact of posterior occlusal support on the condylar position. *J Oral Rehabil* 31:759–763.
 - 16) Ueno T, Baba K, Fueki K, Ai M, Ohyama T (2000) Influence of protrusive tooth contact on tapping point distribution. *J Oral Rehabil* 27:1004–1011.

Correspondence:

Dr. Shuichiro Yamashita
Department of Removable Partial
Prosthodontics, Tokyo Dental College,
2-9-18 Kanda-Misakicho, Chiyoda-ku,
Tokyo 101-0061, Japan
E-mail: syamashita@tdc.ac.jp