Original article

Comparison of the mandibular hinge axis in adult patients with facial asymmetry with and without posterior unilateral crossbite

Jun-ichi Takada*, Jun J. Miyamoto*, Toshiaki Yokota*, Takashi Ono** and Keiji Moriyama*

*Maxillofacial Orthognathics and **Orthodontic Science, Tokyo Medical and Dental University Graduate School, Japan

Correspondence to: Jun J. Miyamoto, Maxillofacial Orthognathics, Graduate School, Tokyo Medical and Dental University, 1-5-45, Yushima, Bunkyo-ku, Tokyo 113-8549, Japan. E-mail: mjmort@tmd.ac.jp

Summary

Background/Objectives: Although it has been suggested that adult patients with facial asymmetry with posterior unilateral crossbite (PUXB) may have a more tilted mandibular hinge axis (MHA) than those without PUXB, whether craniofacial morphology is associated with the MHA remains unclear. The purpose of this study was to compare the craniofacial morphology and MHA in adult subjects with post-growth facial asymmetry with and without PUXB.

Subjects/Methods: Thirty pre-orthodontic patients (PUXB and non-PUXB groups, n = 15 each, 9 females and 6 males, mean age: 23.2 years) participated in the study. The MHA was measured by computerized axiography and duplicated on posteroanterior and submentovertex cephalometric radiographs. Morphological asymmetry was evaluated for both skeletal and dental components and positional deviation of the mandible by cephalometric analysis. The Mann–Whitney U-test and Spearman's correlation coefficient by rank were used for statistical analysis. The level of statistical significance was set at P < 0.05.

Results: Significant differences in both skeletal and dental components were found between the PUXB and non-PUXB groups. In both the frontal and horizontal dimensions, the inclination of the MHA towards the mandibular shifted side was greater in the PUXB group than in the non-PUXB group.

Conclusions/Implications: The present findings suggest that facially asymmetric adult subjects with malocclusions associated with PUXB exhibit not only mandibular asymmetry but also remodelling of the condylar head and glenoid fossa that accompanies the three-dimensional shifting of the MHA.

Introduction

Many investigators have reported human craniofacial asymmetry in the frontal plane (1, 2). Severt and Proffit (3) investigated 1460 patients in terms of facial asymmetry and found that 40 per cent of skeletal Class III subjects showed facial asymmetry in the mandible. Moreover, Schmid et al. (4) showed that a bilateral difference in the mandibular ramus length causes facial asymmetry. Furthermore, subjects with facial asymmetry reportedly had asymmetric deformity of not only the outer surface but also of the inner structure [e.g. the dental arch form and buccal/lingual pressure (5–7)] when comparing the left and right sides.

Morphological asymmetry has been observed in the temporomandibular joint (TMJ) region as well as the dental arch. Pirttiniemi et al. (8) reported that among subjects with posterior unilateral crossbite (PUXB), the height of the articular eminence on the shifted side of the mandible was significantly different from that on the contralateral side. Langberg et al. (9) investigated the prevalence of mandibular shift in adult subjects...
with PUXB using a condylar position indicator. Because they found no subjects with lateral functional mandibular shift and no significant differences in condylar position within the glenoid fossa between the PUXB and control groups, they suggested that long-term adaptive repositioning of the condylar head and glenoid fossa had occurred in these adult subjects with PUXB. Brian et al. (10) also reported that in Angle Class I adult subjects with PUXB, the mandible is rotated further horizontally towards the side of the PUXB than in normal subjects. Consequently, the condyle ipsilateral to the PUXB is located more posteriorly than that contralateral to the PUXB. These previous findings suggest that subjects with both PUXB and facial asymmetry may have asymmetric deformity of not only the maxillary and mandibular dental arches but also of the position of the glenoid fossa through progressive asymmetric compensation of the condyle–fossa relationship.

Mandibular movement occurs as a complex series of interrelated three-dimensional rotational and translational activities (11). A previous study reported that morphological asymmetry of the mandible was closely related to mandibular translational movement (12). However, the relationship between mandibular rotational movement, which occurs around the mandibular hinge axis (MHA), and morphological asymmetry remains unclear.

Slavicek (13, 14) indicated that evaluation of the MHA is an accessory diagnostic protocol for stomatognathic dysfunction and for functional evaluation before and after orthodontic treatment. In terms of clinical implications, many previous studies suggested that evaluation of the MHA is important for maxillofacial surgeons and orthodontists when performing maxillary surgery with rotation of the mandible (15–18).

Furthermore, many studies have suggested a high possibility that untreated PUXB induces adaptation of the mandible and TMJ to lateral functional mandibular shift in childhood, leading to permanent skeletal asymmetry (19–22). In other words, they confirmed that abnormal growth should be detected early in life to correct or at least decrease the amount of asymmetry. Accordingly, evaluation of the MHA in patients with concurrent facial asymmetry and PUXB has important clinical implications.

Therefore, the aim of the present study was to compare the craniofacial morphology and MHA in adult subjects with post-growth facial asymmetry with and without PUXB. The following null hypothesis was tested: there are no differences in the craniofacial morphology and PUXB between the right and left sides of the mandible. The PA radiograph was taken in the intercuspal position with the Frankfort horizontal (FH) plane parallel to the floor. The SMV radiograph was taken with the FH plane parallel to the film (27). We defined the landmarks and reference lines according to a previous cephalometric study with some added modification (22, 27–30). The angle between MHA and LO line and angle between IMHA and ISL were defined as the angles formed by the line that connected the bilateral CoRs and LO line or ISL on the right and left sides of the mandible. The exclusion criteria were as follows: 1. Skeletal Class II malocclusion. 2. Functional lateral shift of the mandible. 3. Congenital malformations, including clefting and TMJ dysfunction. 4. Current treatment with any medication known to affect muscle activity.

Oral and functional examination of all subjects was performed by three orthodontists who were certified by the Japanese Orthodontic Society (JT, JJM, and KM).

The sample size was estimated to be 30 subjects for an effect size of 1 (24) for the angle between MHA and LO line variable, with a power calculation of 0.80 and an alpha of 0.05 [G*Power, version 3.1.7; (25)].

**Determination of the MHA using cephalometric radiographs**

As described in a previous study, the bilateral centres of rotation (CoRs) of mandibular motion were measured by computerized axiography (CADIAX; Gamma Dental, Klosterneuburg, Austria) at least three times and duplicated on posteroanterior (PA) and submentovertex (SMV) cephalometric radiographs (26). The MHA/IMHA was defined as the line that connected the bilateral CoRs (Figure 1).

**Cephalometric analysis**

A pair of PA and SMV cephalometric radiographs was taken using a cephalostat (FUFIX FCR7000; Fujifilm, Tokyo, Japan) to simultaneously evaluate the inclination of the MHA in reference to the cranio and evaluate the morphological difference between the right and left sides of the mandible. The PA radiograph was taken in the intercuspal position with the Frankfort horizontal (FH) plane parallel to the floor. The SMV radiograph was taken with the FH plane parallel to the film (27). We defined the landmarks and reference lines according to a previous cephalometric study with some added modification (22, 27–30). The angle between MHA and LO line and angle between IMHA and ISL were defined as the angles formed by the line that connected the bilateral CoRs and LO line or ISL on the PA and SMV radiographs, respectively (Figures 2 and 3).

For paired structures, the distance and angle to the reference axis were determined for both landmarks, and the bilateral difference was calculated. The bilateral CoRs were determined by the same investigator (JT) to exclude inter-examiner error. Moreover, the same investigator traced all cephalometric radiographs and calculated each

**Materials and methods**

**Subjects**

Thirty adult subjects with and without facial asymmetry participated after giving fully informed consent as provided in the protocol approved by the institutional ethics committee (approval #639). They were divided into two groups (n = 15 each): PUXB [9 females and 6 males, 23.5 ± 7.6 (mean ± standard deviation) years of age] and non-PUXB (9 females and 6 males, 22.8 ± 5.8 years of age).

Each patient fulfilled the following criteria: 1. Skeletal Class I or Class III malocclusion with an ANB angle of less than 2 degrees and overjet of less than 4 mm (Table 1). 2. Full permanent dentition with the exception of the third molars and no oral habits. 3. Post-growth adult subjects over 18 years of age. The Cervical Vertebrae Maturation method (23) was used to assess the lateral cephalograms, and all subjects were in C5, C6. 4. No previous orthodontic treatment. 5. Posterior crossbite, defined as a minimum of two teeth on one side of the dentition.

---

**Table 1. Comparison of lateral cephalometric analysis with and without PUXB. PUXB, posterior unilateral crossbite; SD, standard deviation**

<table>
<thead>
<tr>
<th></th>
<th>PUXB Mean</th>
<th>PUXB SD</th>
<th>Non-PUXB Mean</th>
<th>Non-PUXB SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Angular</strong></td>
<td><strong>Mean</strong></td>
<td><strong>SD</strong></td>
<td><strong>Mean</strong></td>
<td><strong>SD</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>SNA</td>
<td>80.6</td>
<td>3.8</td>
<td>80.5</td>
<td>3.2</td>
<td>0.740</td>
</tr>
<tr>
<td>SNB</td>
<td>82.5</td>
<td>3.9</td>
<td>83.8</td>
<td>3.8</td>
<td>0.430</td>
</tr>
<tr>
<td>ANB</td>
<td>–1.9</td>
<td>1.6</td>
<td>–3.3</td>
<td>2.7</td>
<td>0.165</td>
</tr>
<tr>
<td>Mandibular plane</td>
<td>28.9</td>
<td>3.7</td>
<td>26.7</td>
<td>4.6</td>
<td>0.120</td>
</tr>
<tr>
<td>Facial angle</td>
<td>89.8</td>
<td>3.1</td>
<td>91.5</td>
<td>3.0</td>
<td>0.130</td>
</tr>
<tr>
<td>U1-SN</td>
<td>107.9</td>
<td>7.0</td>
<td>112.9</td>
<td>8.3</td>
<td>0.059</td>
</tr>
<tr>
<td>L1-MP</td>
<td>79.6</td>
<td>7.4</td>
<td>82.5</td>
<td>5.5</td>
<td>0.309</td>
</tr>
<tr>
<td><strong>Linear</strong></td>
<td><strong>Mean</strong></td>
<td><strong>SD</strong></td>
<td><strong>Mean</strong></td>
<td><strong>SD</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>OJ</td>
<td>–2.3</td>
<td>1.6</td>
<td>–2.2</td>
<td>1.7</td>
<td>0.604</td>
</tr>
<tr>
<td>OB</td>
<td>0.7</td>
<td>1.8</td>
<td>0.6</td>
<td>1.8</td>
<td>0.705</td>
</tr>
</tbody>
</table>
Determination of the mandibular hinge axis. (A) Oblique view of the computerized axiogram. (B) Marking of the centre of rotation (CoR). (C) Representative PA (upper) and SMV (lower) cephalometric radiographs with marks of CoRs. Abbreviations: PA, posteroanterior; SMV, submentovertex.

Landmarks, reference planes, and linear/angular measurements on the PA cephalometric radiograph. (A) Landmarks: 1, intersection of zygomaticofrontal suture and orbita: LO, LO'; 2, centre of the root of the zygomatic arch: ZA, ZA'; 3, neck of crista galli; most constricted point of projection of perpendicular lamina of ethmoid: CG; 4, upper point of the anterior nasal spine: ANS; 5, proximal incisal point between the maxillary central incisors: U1; 6, proximal incisal point between the mandibular central incisors: L1; 7, contact area of the maxillary and mandibular first molars: CA, CA'; 8, buccal contour crest of the mandibular first molar: L6, L6'; 10, intersection of tuber maxilla and zygomatic arch on the jugular process: Mx, Mx'; 11, lateral and inferior border of the antegonial notch: AG, AG'; 12, most inferior aspect of the mandibular symphysis: Me. (B) Reference planes and linear measurements: the line perpendicular to the LO line that passes through CG: MSP; Facial plane; the line connecting LO and AG: FP; Occlusal plane; the line connecting CA and CA': OP; Maxillary plane; the line connecting MX and MX': MP; 1, upper intermolar width; distance from U6 to U6' along the occlusal plane: U6; 2, lower intermolar width; distance from L6 to L6' along the occlusal plane: L6; 3, maxillary dental midline to midsagittal plane: U1; 4, mandibular dental midline to midsagittal plane: L1; 5, maxillary and mandibular dental midline distance along the occlusal plane: L1/U1; 6, maxillary base width; distance from MX to MX': Mx; 7, facial width; distance from ZA to ZA': ZA; 8, maxillary molar-facial plane distance: U6/FP; 9, mandibular molar-facial plane distance: L6/FP; 10, menton-midsagittal plane distance: Me. (C) Reference planes and angular measurements: 1, positional symmetry angle, the angle LO-ZA-AG on the right side and LO'-ZA'-AG' on the left side: LO-ZA-AG, LO-ZA'-AG'; 2, transverse maxillary positional angle, the angle formed by the CG-ANS line and MSP: ANS/MSP; 3, transverse mandibular positional angle, the angle formed by the CG-Me line and MSP: Me/MSP; 4, occlusal angle; the angle formed by the LO line and OP: Op; 5, maxillary angle; the angle formed by the Mx-Mx' line and the LO line: Mx/LO; 6, mandibular hinge axis (MHA); the angle formed by the MHA and the LO line: angle between MHA and LO line. a and b denote landmarks on the right and left sides, respectively, of the cephalometric tracings.

Method error

Overall, the mean ± standard deviation of the method error was 0.2 ± 0.2 degrees for angular measurements and 0.2 ± 0.3 mm for linear measurements. When compared with previous studies, no systematic errors were found (31–33).

Statistical analysis

The evaluation of differences in the linear and angular measurements between subjects with and without PUXB was subjected to the Mann–Whitney U-test. Spearman’s rank correlation coefficient was used to evaluate the relationships between angle between MHA and LO line/angle between IMHA and ISL and each linear and angular measurement. All procedures were performed with statistical software (SPSS10.0; SPSS, Chicago, Illinois, USA). A threshold of P < 0.05 was considered to be statistically significant.

Results

Method error

The evaluation of differences in the linear and angular measurements between subjects with and without PUXB was subjected to the Mann–Whitney U-test. Spearman’s rank correlation coefficient was used to evaluate the relationships between angle between MHA and LO line/angle between IMHA and ISL and each linear and angular measurement. All procedures were performed with statistical software (SPSS10.0; SPSS, Chicago, Illinois, USA). A threshold of P < 0.05 was considered to be statistically significant.
Linear and angular measurements on PA radiographs

The L1/L1/U1, Me, ANS/MSP, Me/MSP, Mx-LO, Op, and L6-U6 were significantly larger in the PUXB group than in the non-PUXB group, while the L6/FP was significantly smaller in the PUXB group than in the non-PUXB group (Table 2). The angle between MHA and LO line in the PUXB group was significantly larger than that in the non-PUXB group.

Linear and angular measurements on SMV radiographs

The L6-MSP, Sy, and Sy-Ba were significantly larger in the PUXB group than in the non-PUXB group, while the Co/Sy, Co/L1, and L6/ISL were significantly smaller in the PUXB group than in the non-PUXB group (Table 2). The angle between IMHA and ISL in the PUXB group was significantly larger than that in the non-PUXB group.

Discussion

Our study is the first to show a significant difference in the angle between MHA and LO line/angle between IMHA and ISL between PUXB and non-PUXB groups using both PA and SMV cephalometric radiographs. Moreover, there were significant differences in both skeletal and dental components between the PUXB and non-PUXB groups. Since the samples were collected from patients seeking for treatment, it should be noted that the findings of the study are not representative of the general population. Moreover, the samples were limited to skeletal Class I and Class III and that the results cannot be extrapolated to skeletal Class II subjects.

Identification of the MHA/IMHA

It is known that the mandibular axis rotation is meaningful for studying the physiology and pathophysiology of the mandibular movement in the stomatognathic system (13, 14, 34). Although no previous studies have investigated the functional aspects of the MHA using PA and/or SMV cephalometric radiographs in adult subjects with PUXB, it is extremely important to assess the MHA/IMHA because it may affect not only mandibular motion but also craniofacial morphology. We were careful to ensure high reproducibility.

Table 2. Comparison of linear and angular measurements. (A) Linear measurements: 1, angle formed by FRP and Co and Sy; 2, condylion to mandibular midline distance: Co-L1; 3, mandibular first molar to mandibular midline distance: L6-L1; 4, condylion to midsagittal plane distance: Co-MSP; 5, midsagittal plane to mandibular first molar plane: L6-MSP; 6, mandibular first molar to midsagittal plane distance: L6/MSP; 7, midsagittal plane to symphyseal distance: Sy. (B) Reference planes: 1, angle formed by FRP and CO; 2, line connecting Co/Sy and Co/MSP; 3, line connecting Co/Sy and Co-L1; 4, line connecting Co/MSP and Co-L1; 5, line connecting Co/Sy and Co-L1; 6, line connecting Co/Sy and Co-MSP; 7, line connecting Co/MSP and Co-L1.

Table 2. Comparison of linear and angular measurements. (A) Linear measurements: 1, angle formed by FRP and Co and Sy; 2, condylion to mandibular midline distance: Co-L1; 3, mandibular first molar to mandibular midline distance: L6-L1; 4, condylion to midsagittal plane distance: Co-MSP; 5, midsagittal plane to mandibular first molar plane: L6-MSP; 6, mandibular first molar to midsagittal plane distance: L6/MSP; 7, midsagittal plane to symphyseal distance: Sy. (B) Reference planes: 1, angle formed by FRP and CO; 2, line connecting Co/Sy and Co/MSP; 3, line connecting Co/Sy and Co-L1; 4, line connecting Co/MSP and Co-L1; 5, line connecting Co/Sy and Co-L1; 6, line connecting Co/Sy and Co-MSP; 7, line connecting Co/MSP and Co-L1.

**P < 0.01, *P < 0.05.
Comparisons of dentoalveolar and skeletal features between subjects with and without PUXB

A previous study compared dentoalveolar and skeletal features between subjects with and without PUXB in childhood, and their findings were similar to those found in adulthood in the present study (22). With regards to dentoalveolar features, there were significant differences in the mandibular arch width in the PA dimension between adult subjects with and without PUXB. Moreover, they reported that in skeletal measurements, there were significant differences in not only the mandibular shift to the cranium but also the relative horizontal position (9). Thus, previous studies have suggested a discrepancy in dental arch width and mandibular asymmetry in subjects with PUXB in childhood (22) and adulthood (9).

Although there were no significant dentoalveolar differences in the maxillary width or mandibular arch width, we found that there were significant differences in the L6-U6 between subjects with and without PUXB. Therefore, the present study found discrepancy in the dental arch form as demonstrated in previous studies. Moreover, there were significant differences in the mesiodistal and buccolingual positions (i.e. L6-FP, L6-MSP, and L6-LSL) in the mandibular first molar. For the sample selection, our study excluded subjects with mandibular midline deviation caused by crowding. Thus, the positional difference in the mandibular molar suggests that the mandibular molar was positioned buccodistally on the shifted side, resulting in the bilateral morphological difference in the mandible and glenoid fossa.

Skeletal discrepancies in mandibular deviation were revealed between subjects with and without PUXB with reference to the cranial (i.e. Me, Me-MSP, and Sy-8a) and the maxillary–mandibular relative deviation (i.e. L1/U1), which supports the findings in a previous study (9). Furthermore, there were significant differences in the maxillary (i.e. ANS/MSP and Mx-LO) and occlusal plane (i.e. Op) deviations. Together with the findings in a previous study that reported the achievement of symmetrical condylar positioning after maxillary expansion in juvenile subjects with PUXB, it was suggested that the discrepancy between the maxillary and mandibular arch widths may influence residual symptoms of not only mandibular growth but also maxillary growth (19, 20). However, further longitudinal studies following non-interventional cases of juvenile subjects with PUXB may help to clarify the cause–effect relationship between the morphological and functional aspects of subjects with PUXB.

Comparisons of the MHA/IMHA between subjects with and without PUXB

The method used to study the morphology of the condyle and/or glenoid fossa that carried suspicion of skeletal asymmetry was mostly cephalometric measurement. A difference between shift-side and non-shift-side condyles in subjects with PUXB in childhood was reported. Moreover, the bilateral difference in the condyle and mandible was corrected after expansion of the maxillary arch using SMV radiographs (21, 22). In this study, functional and anatomical methods were combined to determine the inclination of the MHA/IMHA. The MHA was significantly tilted superior to the side of the PUXB on the PA radiographs, while the IMHA was significantly tilted posterior to the side of the PUXB on the SMV radiographs. As mentioned above, the MHA was located inside the condyle. This is in agreement with the findings in a previous study in which adaptive repositioning of the condylar head and glenoid fossa had occurred (9). In another previous study, the mandible of the subjects with PUXB was considered to be rotated in relation to the cranial floor; although there was no mandibular asymmetry (10). The authors suggested that the condylar head and glenoid fossa on the shifted side had been remodelled. In our study, the subjects with PUXB had a greater mandibular deviation (5.8±3.0 mm measured at Me) than that in the study by Brian et al. (10). Therefore, the subjects of our study exhibited both changes in the MHA/IMHA and bony asymmetry of the mandible. Thus, it could be difficult to fully correct yaw axis in adult asymmetry patients in orthognathic surgery.

Although the MHA/IMHA was significantly different with and without PUXB, the amount of difference was very small [1.3 degrees of MHA inclination (standard deviation: 1.0) and 1.0 of IMHA (standard deviation: 0.8–0.6)]. In the three-dimensional image analysis, previous studies reported the condyle–fossa relationship ipsilateral to the PUXB is located more posterosuperiorly than that contralateral to the PUXB (35, 36). Consequently, our findings were in line with those in the previous studies. Nevertheless, one should be aware that the clinical application of our findings is limited, because of the small difference.

Conclusions

The null hypothesis that there are no differences in the craniofacial morphology or MHA between facially asymmetric adult subjects with and without PUXB was discarded. Rather, the MHA/IMHA in subjects with PUXB was significantly tilted compared with that in subjects without PUXB in both the frontal and horizontal dimensions. Thus, it appears that facially asymmetric adult subjects with malocclusions associated with PUXB exhibit not only mandibular asymmetry but also remodelling of the condylar head and glenoid fossa that accompanies the three-dimensional shifting of the MHA. However, whether there is asymmetry during the pre-growth period in post-growth facially asymmetric patients with PUXB remains unclear. Thus, we would like to clarify the relationship between the craniofacial morphology and MHA in pre-growth facially asymmetric subjects with PUXB in a further study. It is noteworthy that the present study involved simultaneous two-dimensional image analysis with limited accuracy and reliability. It is obvious that further studies should be conducted to clarify the interaction of detailed morphological and functional aspects using three-dimensional image analysis with the greater accuracy and reliability, and serial mandibular movement with our modified approach. This would help with the conclusions of our study, especially those regarding the condylar height and glenoid fossa remodelling.

Funding

Grants-in-Aid for Scientific Research Projects from the Japan Society for the Promotion of Science (#22792036, 25862001) and the ‘International Research Center for Molecular Science in Tooth and Bone Diseases’, part of the Japanese Ministry of Education, Global Center of Excellence Program.

Acknowledgements

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.
References


