Inclination of the occlusal plane is associated with the direction of the masticatory movement path

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SUMMARY Using lateral cephalograms and a jaw movement-recording system, the relationship between the masticatory movement path and dentofacial morphology was investigated in 17 subjects (9 males and 8 females, mean age 23.5 years) without a history of orthodontic treatment. The masticatory movement path was measured at the right and left lower first molar while the subjects chewed gum. The angle between the Frankfort horizontal plane and the masticatory axis (FH-masticatory angle), defined as the axis passing the opening and closing turning point on the sagittal masticatory path, was also measured. The correlation between the angular measurements derived from the lateral cephalogram and the FH-masticatory angle was then investigated.

A positive correlation was observed in the FH-masticatory, occlusal plane ($P < 0.05$), and mandibular plane ($P < 0.01$) angles. Furthermore, it was found that the angle between the masticatory axis and the occlusal plane ($69.1 \pm 4.2$ degrees) remained constant even as the masticatory axis showed a tendency to incline forward as the mandibular plane angle became steeper; the rates of change of the FH-masticatory and the occlusal plane angles were approximately 1:1. This finding suggests that the masticatory movement path is closely associated with the occlusal plane.

Introduction

Clinical studies have indicated that functions of the body are mutually related to dentofacial morphology (Harvold, 1963; Moss and Salentijn, 1969) and that the maxilla, mandible, teeth, temporomandibular joints (TMJs), and masticatory muscles correspond to stomatognathic function (Moss, 1981). Occlusal interdigitation that does not complement function in this setting after orthodontic treatment may result in relapse and/or the onset of stomatognathic dysfunction.

Masticatory movement, a stomatognathic function, complements the functions of the mandible, tongue, and face in relation to the central nervous system (Lund, 1991; Nakamura and Katakura, 1995). The masticatory function regulatory mechanism modulates rhythmic jaw movements via sensory feedback from mechanoreceptors in the periodontal tissues regarding the masticatory force and the direction of force loaded onto the teeth (Appenteng et al., 1982; Ramfjord and Ash, 1983; Lavigne et al., 1987; Inoue et al., 1989; Yamamura and Shimada, 1993).

Sassouni (1969) reported a tendency that if the mandibular plane angle is smaller, bite force is larger, and conversely, if the mandibular plane angle is larger, bite force is smaller. These findings show a part of relationship between dentofacial morphology and stomatognathic function. However, it is important to consider not only force strength, but also the direction of the force.

Although, it is thought that the masseter muscle is especially related to the factor in which the direction of masticatory movement is decided, other masticatory and facial muscles also affect the direction of masticatory movement. Therefore, this study investigated the masticatory movement path generated with harmonized movement of the muscles. The aim was to verify a hypothesis that some relationships are observed between maxillofacial morphology and the masticatory movement path.

Subjects and methods

Subjects

Seventeen healthy adults (9 males and 8 females, mean age 23.5 years) who had no restorations covering the cusp tips, no TMJ symptoms, and no history of orthodontic treatment were examined. The aim of the study was explained to the subjects, who all provided their informed consent to participate. The study was approved by the ethics committee of Nihon University School of Dentistry (number 2003-19).

Measurement of mandibular movement

Masticatory movement was recorded using the Gnatho-hexagraph (JM-1000H, Ono Sokki Manufacturing Co., Ltd, Yokohama, Japan). The installation and recording methods were performed following the guidelines of Miyawaki et al.
The accuracy of the Gnathohexagraph has previously been demonstrated (Tokiwa et al., 1996; Tokiwa, 2001).

The subjects were seated on chairs, with their heads in a fixed position. The co-ordinates of the right and left upper margins of the tragus and orbital, as well as those of the mesio-buccal cusp tips of the lower first molar, were recorded using the LED pointer of the gnathohexagraph. Chewing gum (Freezone, Lotte Co., Ltd, Tokyo, Japan) was used for the measurement of masticatory movement. Before measurement, the subjects chewed the gum for 1 minute to soften it, and centric occlusion was then fixed as the starting position for masticatory movement recording. The subjects chewed 15 times on both the right and left sides of their mouths, and the masticatory path of the lower first molar on the working side was recorded. These measurements were obtained by one author (MS).

**Definition of the masticatory axis**

The sagittal movement path was evaluated to compare the recorded masticatory path with measurements from the lateral cephalograms (Figure 1A). The masticatory axis was defined as the axis passing the opening and closing turning point on the sagittal masticatory path (Figure 1B). The average masticatory axis during 15 cycles and the FH plane were measured. The mean values of the right and left angles were then calculated and compared with the cephalometric measurements (Figure 2).

**Morphometry**

The angles between the FH plane and the occlusal (FH-Occ), mandibular (FH-Mand), and SN (FH-SN) planes, as well as SNA, SNB, and ANB, were measured (Figure 3). One examiner (MS) traced and measured all the radiographs to eliminate interexaminer errors. All the tracings and measurements were performed at least twice with an interval of 1 month to reduce intraexaminer errors, and the mean values were used. When there was more than a 1-degree difference in the measurements, the tracing was remeasured and the mean value of the three measurements was used.
Statistical analysis

Pearson’s correlation coefficient between the FH-masticatory angle and the cephalometric measurements was calculated. FH-Occ was designated as an independent variable in order to examine the relationship between the FH-masticatory angle and the occlusal plane, and regression analysis was used for the FH-masticatory angle. The statistical analyses were performed using SPSS for Windows version 8.0J (SPSS Inc., Tokyo, Japan).

Results

Table 1 shows the descriptive statistics for the FH-masticatory angle and the cephalometric measurements. The ANB ranged from −1.5 to 7.0 degrees and the Frankfort mandibular plane angle from 14.5 to 36.0 degrees. Thus, the study included subjects with various skeletal abnormalities.

The correlation coefficient between the FH-masticatory angle and the cephalometric measurements is shown in Table 2. The FH-masticatory angle demonstrated significant correlation with FH-Occ and FH-Mand. The data indicated that as the FH-masticatory angle increased, FH-Occ and FH-Mand also increased; however, no other significant correlation was observed.

A correlation of the FH-masticatory angle and FH-Occ is shown in Figure 4. The regression coefficient was 0.97, indicating an almost 1:1 ratio for the rates of change of the FH-masticatory angle and FH-Occ. Therefore, the angle between the FH-masticatory axis and the occlusal plane appeared to be constant.

Discussion

The gnathohexagraph has a small facebow, and the burden on the patient is reduced compared with previous jaw movement-recording systems. In addition, it can record arbitrary points, which are useful in the study of the masticatory movement path (Hannnam, 1991; Tokiwa et al., 1996; Palla et al., 1997; Huddleston Slater et al., 1999; Miyawaki et al., 2000; Tokiwa, 2001).

Previous masticatory movement investigations have attempted to clarify the masticatory mechanism (Ottenhoff et al., 1993; Slagter et al., 1993; Daet et al., 1995; Miyawaki et al., 2000; Beata et al., 2003; Hayasaki et al., 2003; Naeije and Hofman, 2003); however, these studies largely focused on incisor and condylar points, despite the fact that food crushing and tearing occur on the masticatory surfaces of the molars. Movement of the lower central incisor point differs from that of the lower first molar during mastication (Gibbs et al., 1981; Gibbs and Lundeen, 1982). Stresses and strains can be observed on the masticatory surface of the first molar during the terminal occlusal phase and can affect maxillo-mandibular formation (Korioth, 1990). For these reasons, the masticatory path of the first molar was recorded.

The sagittal masticatory path of the first molar, which is considered a simple parameter for masticatory functions, was compared with cephalometric measurements. The present study defined the masticatory axis as that passing the opening and closing turning point on the sagittal masticatory path. The superior turning point of closing to opening is the intercuspal position (i.e. centric occlusion; Hayasaki et al., 2003) and is thought to be stable in adults without abnormal TMJs or malocclusion. The inferior turning point is affected by the anatomical morphology of the TMJ (Yatabe et al., 1995, 1997; Naeije, 2003), the solidity and size of the food bolus (Bilt et al., 1991; Miyawaki et al., 2000), and the muscle reflective activity, strength, and operation. The inclination of the masticatory axis is alternated according to the location of the inferior turning point. Prior to measurement, the chewing gum used in the study was chewed for 1 minute to soften it in order to eliminate recording errors due to inconsistency in texture.

The results demonstrated a positive correlation in the inclination between the masticatory axis and the mandibular plane when measured relative to the FH plane (Table 2). As the angle between the FH plane and the masticatory axis increased, the angle of the FH plane and the mandibular plane also increased. The masticatory axis inclined forward in the subjects with a high angle (i.e. dolichofacial type). A positive correlation was also shown in the inclination between the masticatory axis and the occlusal plane (Table 2). When a larger masticatory angle was observed, a larger occlusal plane angle was also found; accordingly, when the occlusal plane was steep, the masticatory axis inclined forward.

The regression coefficient was 0.97, which indicates a 1:1 ratio for the rate of change in the inclination of the

Table 1  Means and standard deviations (SDs) of the FH-masticatory angle and cephalometric measurements (degrees).

<table>
<thead>
<tr>
<th></th>
<th>FH-masticatory angle</th>
<th>Occ-masticatory angle</th>
<th>FH-Occ</th>
<th>FH-SN</th>
<th>FH-Mand</th>
<th>ANB</th>
<th>SNA</th>
<th>SNB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>18.0</td>
<td>61.3</td>
<td>0.5</td>
<td>4.5</td>
<td>14.5</td>
<td>−1.5</td>
<td>74.5</td>
<td>71.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>39.9</td>
<td>75.0</td>
<td>14.5</td>
<td>13.5</td>
<td>36.0</td>
<td>7.0</td>
<td>84.5</td>
<td>85.0</td>
</tr>
<tr>
<td>Mean</td>
<td>27.7</td>
<td>69.1</td>
<td>6.79</td>
<td>9.06</td>
<td>25.00</td>
<td>2.29</td>
<td>80.4</td>
<td>78.1</td>
</tr>
<tr>
<td>SD</td>
<td>5.77</td>
<td>4.20</td>
<td>4.08</td>
<td>3.05</td>
<td>7.42</td>
<td>2.20</td>
<td>2.54</td>
<td>3.32</td>
</tr>
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masticatory axis and occlusal plane. The angle between the masticatory axis and occlusal plane remained constant (approximately 69 degrees), regardless of the inter-skeletal variation among the subjects. The masticatory axis and the occlusal plane showed a tendency to incline forward with a high angle, thus maintaining a constant angle.

Sassouni and Nanda (1964), Proctor and DeVincezon (1970), and DiPietro and Moergeli (1976) investigated the relationship between the masseter muscle and the occlusal plane and reported that the occlusal plane becomes steeper and the masseter muscle inclines forward as the mandibular plane becomes steeper. Proctor and DeVincezon (1970) showed that the angle between the anterior border of the masseter muscle and the occlusal plane remained at approximately 69 degrees—a value similar to that of the angle of the masticatory axis and the occlusal plane in the present study, suggesting that one of the factors determining the inclination of the masticatory axis is related to conditions such as muscle activity and the operation of the anterior border of the masseter muscle.

Ogawa et al. (1998b) reported a correlation between the occlusal plane and the masticatory path of closure, in which the masticatory closing path and the occlusal plane maintained a consistent perpendicular relationship with each other regardless of the interindividual variation in occlusal plane inclination. Notably, Ogawa et al. (1998a) recorded masticatory movement using the incisor point, which resulted in differences between their findings and those of the present study. However, the results of both investigations confirm that there is a constant relationship in sagittal inclination between masticatory movement and the occlusal plane.

Conclusions

The present study replaced complex masticatory movement with the masticatory axis as a simple parameter of masticatory function. The results suggest that the masticatory axis is significantly correlated with the occlusal plane, involving agreement between stomatognathic function and dentofacial morphology during growth and development. Occlusal alteration caused by orthodontic treatment can be a factor in relapse and disharmony between functional movement and dentofacial morphology.

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