Proposal of quantitative method for determining occlusal plane

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Abstract: Purpose: The purpose of this study is to investigate the relationship between the occlusal plane and the least motion axis (LMA) that has the minimum range of motion of the mandible in the sagittal plane.

Material and Methods: Forty-five volunteers (24 males, 21 females, 26.7 ± 6.6 yrs) with asymptomatic TMJs participated in this study. An electro-magnetic jaw tracking device was employed to record the sagittal border jaw movement and habitual open-close movement, which started from the ICP, with a sampling rate of 100 Hz. The LMA was estimated from the sagittal border jaw movement using estimating algorithm of our own. In this study, the occlusal plane was defined as the plane pass through three reference points: incisal point (IN) and the central fossa points of right/left first molars (R6, L6) of the upper dentition. The horizontal plane containing the incisor point (IN) and the LMA could be defined as the IN-LMA plane. The closing sagittal angles relative to the occlusal plane (CA\textsuperscript{OCCL}) and those relative to the IN-LMA plane (CA\textsuperscript{LMA}) were analyzed. The path of habitual open-close movement of the IN and M6 (the central points of R6 and L6) were projected on the sagittal plane, and the CA\textsuperscript{OCCL} and the CA\textsuperscript{LMA} of the incisor and molar closing paths at 5.0 mm incisal closing level were calculated and compared.

Result: The mean values of the CA\textsuperscript{OCCL} and the CA\textsuperscript{LMA} of the incisal path (mean±SD) were 79.47±8.40 degrees and 78.97±7.76 degrees, respectively. There was no significant difference between both planes (paired t-test: p > 0.05). The mean values of the CA\textsuperscript{OCCL} and the CA\textsuperscript{OCCL} of the molar path were 75.32±11.92 degrees and 74.82±10.94 degrees, respectively. There was also no significant difference between both planes (paired t-test: p > 0.05). In addition, there was a strong correlation between the CA\textsuperscript{OCCL} and the CA\textsuperscript{LMA}. The Pearson’s correlation coefficient for the incisor path was \( r = 0.807 \) (p < 0.05), and was \( r = 0.908 \) (p < 0.05) for the molar path. The slope of regression line was 0.99 for the incisor path, and 0.98 for the molar path. Consequently, the IN-LMA plane nearly corresponded with the upper occlusal plane.

Conclusion: As a result of this study, it was considered that the method using the LMA for quantitatively determining the occlusal plane is an appropriate means anatomically and functionally.
I. Introduction

Occlusal plane is one of the horizontal reference planes in the cranio-mandibular component, which is defined as the average plane established by the incisal and occlusal surface of the tooth. Furthermore, occlusal plane involve a curve which is called Spee's curve. This plane is an important index for restoring the occlusion aesthetically and functionally. Depending on the purpose of use, it was proposed to divide the occlusal plane into anterior and posterior planes. The anterior occlusal plane is used for aesthetic restoration in the anterior tooth region. On the other hand, the posterior occlusal plane can be used to restore/improve the oral function in the molar region.

In clinic, the occlusal plane is morphologically evaluated using the locational relation to other anatomical planes, such as Camper's plane, Frankfurt plane, and Hamulus-incisive-papilla plane. However, the location of the occlusal plane in natural dentition related to the anatomical plane has a great interindividual variation. Various authors have postulated various anatomical landmarks for determining the occlusal plane. However, none of them is considered as a perfect one that could be used to orient the ideal occlusal plane. Further, there is no objective method using anatomical landmarks for determination of the occlusal plane, because it is a highly subjective relation. It is required to investigate the objective method.

It is important for dentist to accommodate the occlusal plane to jaw functions, because the ideal occlusal plane position is well-defined by functional as well as anatomical requirements. However, there are few studies on functional landmarks for the occlusal plane determination. The occlusal plane should be in proper location and orientation to obtain the most efficient bite force. In 1979, Okane et al. reported that the anteroposterior inclination of the occlusal plane tends to affect the biting force, and the method with Camper's plane seems to be the most reasonable for occlusal plane orientation. In addition, the relationship between the occlusal plane and jaw motion has also been investigated. In 1998, Ogawa et al. investigated the relationship between the occlusal plane inclination and masticatory movement paths. They concluded that there is regularity in the relationship between the occlusal plane and the closing movement path.

We found a new rotation axis of mandible named the least motion axis (LMA) that has the minimum range of motion of the mandible in the sagittal plane. The translation of mandible is said to minimize in the area of mandibular foramen due to reduce the stretch of the inferior alveolar neurovascular bundle. Moreover, in 2017, Zhou et al. reported that more than 80.0% of the mandibular foramina were 4.5 mm below the occlusal plane, and also mandibular lingula were 5.9 mm above the occlusal plane, namely the occlusal plane passes through the mandibular foramen region. Consequently, we hypothesized that the LMA could be located close to the occlusal plane and be used as the functional landmark for objectively determining the occlusal plane. The purpose of this study is to investigate the relationship between the occlusal plane and the LMA.

II. Subjects and Methods

1) Subjects

Forty-five asymptomatic subjects (24 males, 21 females, Mean age: 26.7 ± 6.6 years) from Tokushima University students and staff participated in this study, after they underwent stomatognathic functional examination. They had no related symptoms of temporomandibular disorders, and no missing teeth except for wisdom teeth. In addition, they had no malocclusion morphologically and functionally. All subjects gave written informed consent to participate in this study approved by the Research Ethics Committee of Tokushima University Hospital (Approval number: 575).

2) Measurement of jaw motion

Jaw motion was recorded with a self-developed electromagnetic six-degree-of-freedom jaw tracking device using a pair of tri-axial coil units. One is a transmitter attached to the upper dentition, and the other is a sensor attached to the lower dentition through the custom-made jigs for each participant. Calibration studies of this device revealed that the resolutions of position and orientation measurements are 3.8 μm translation with 0.0001 degree rotation around the intercuspal position (ICP) and 48 μm translation with 0.034 degree rotation around the maximum jaw opening position.

The sagittal border movement and habitual open-close movements, which started from the ICP, were measured with a sampling rate of 100 Hz, 3 times in each participant. To define the reference coordinate system (Fig. 1), the spatial coordinates of reference points relative to the transmitter coordinate system were recorded with the use of a positioning

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probe prior to data acquisition. In this study, the reference coordinate system (upper jaw coordinate system: $O_1X_1Y_1Z_1$) was defined with the following three reference points of the upper dentition: incisal point (IN) and the central fossa points of upper right/left first molars (R6, L6). The origin of this system is located at the centroid of three reference points. The positive $X_U$-, $Y_U$-, and $Z_U$-axes point in the subject’s anterior, left, and superior directions, respectively. The positive rotation directions are defined by the right-hand rule. The reference coordinate system coincides with a lower coordinate system ($O_LX_LY_LZ_L$) in the ICP. As shown in Fig. 1, the occlusal plane is defined as the plane pass through above mentioned three reference points, thus we used the upper occlusal plane as the reference plane.

3) Estimation procedure for LMA

Estimation procedure for the LMA is performed according to Shigemoto’s method that automatically estimate the kinematic axis (KA)\(^{(20)}\). Estimation procedure includes the setup process and the search process. The setup process of the LMA is exactly the same as Shigemoto’s method. In brief, as shown in Fig. 2, the initial intercondylar axis (ICA) is determined based on the Bonwill triangle (an equilateral triangle with all three side lengths of 100 mm) and the Balkwill angle (20 degrees), and the initial points $P_m$ (m = 1…13) for searching the LMA are arranged at 10 mm intervals on the ICA. The sagittal plane $V_m$ passes through $P_m$ and is perpendicular to the ICA. In the search process, the axis point of the plane $V_m$ minimizing the value of a certain geometric parameter is found, then the best-fitting straight line through the axis points is found using the linear regression. The KA is the rotation axis found by Kohno, the motion range of which is a narrow belt-shaped during the sagittal border movement pathway at the mandibular condylar head area\(^{(21)}\). Therefore, Shigemoto et al.\(^{(20)}\) employed the radial thickness of the sagittal border movement pathway as the geometric parameter for searching the KA. In this study, for searching the LMA, the new geometric parameter was required. First, the average sagittal jaw position during the sagittal border movement was calculated. Next, the distance between the average jaw position and each jaw position was calculated, and the sum of the squares of the distance was employed as the new geometric parameter. Then, the least motion axis point (LMAP$_m$) was obtained on the sagittal plane $V_m$ as a point minimizing the value of the geometric parameter. Finally, using 3D linear regression, the LMA was determined such that the sum of the squares of the perpendicular distances between the LMAP$_m$ and the approximate line was minimized.
4) Closing sagittal angle

The horizontal plane containing the point IN and the LMA could be defined as the IN-LMA plane (Fig. 3). As shown in Fig. 4, the path of incisor point (IN) and of molar points (M6), that was center point of L6 and R6, were used to calculate closing sagittal angles relative to the occlusal plane (CA\textsubscript{OCC}) and those relative to the IN-LMA plane (CA\textsubscript{LMA}). The habitual open-close movement path of the IN and M6 were projected on the sagittal plane, and the CA\textsubscript{OCC} and the CA\textsubscript{LMA} of the incisor and molar closing paths at 5.0 mm incisal closing level were calculated and compared. The mean value of 3 times measurement was used as representative value in each subject.

5) Statistical analysis

Statistical analysis was carried out using SPSS 12.0J (SPSS Japan Inc. Tokyo, Japan) with a significance level set at \( p < 0.05 \). A paired t-test was used to compare the CA\textsubscript{OCC} and the CA\textsubscript{LMA}. The linear correlation in the closing angles for two horizontal planes was performed with Spearman's test.

III. Results

Representative estimation results are illustrated in Fig. 3. The LMA was found approximately 30 mm below the ICA. The overall average of the quadratic mean perpendicular distance from LMAP\textsubscript{m} to the LMA (mean±SD; \( n=45 \)) was 0.13±0.21 mm. The overall average of z-coordinate value of LMAP\textsubscript{m} relative to the occlusal plane was \( -0.63\pm7.12 \) mm. The mean values of the CA\textsubscript{OCC} and the CA\textsubscript{LMA} of the incisal path were 79.47±8.40 degrees and 78.97±7.76 degrees, respectively. There was no significant difference between both planes (paired t-test: \( p > 0.05 \)) (Fig.5). The mean values of the CA\textsubscript{OCC} and CA\textsubscript{LMA} of the molar path were 75.32±11.92 degrees and 74.82±10.94 degrees, respectively. There was also no significant difference between both planes (paired t-test: \( p > 0.05 \)) (Fig.6). In addition, there was a strong correlation between the CA\textsubscript{OCC} and the CA\textsubscript{LMA}. The Pearson's correlation coefficient for the incisor path was \( r=0.807 \) (\( p < 0.05 \)), and was \( r=0.908 \) (\( p < 0.05 \)) for the molar path. The slope of regression line was 0.99 for the incisor path, and 0.98 for the molar path. (Fig.7)
IV. Discussions

1) Location of LMA

Shigemoto’s method originally estimated the kinematic axis points (KAPs) and the KA, and reported the average of the quadratic mean perpendicular distance from the KAPs to the KA was 0.36±0.24 mm and the KAPs were located mostly on the KA. In this study, the distance from the LMAPs to the LMA was 0.13±0.21 mm. Therefore, the LMAPs are considered to be located mostly on the LMA.

Ogawa et al.11) described that the sagittal closing angle at 0.5 mm below the ICP relative to the occlusal plane was approximately 90 degrees. When the rotation axis of mandible is located in and around the mandibular condyle, the closing sagittal angle is steeper than 90.0 degrees. As the position of the rotation axis gets closer to the occlusal plane, the closing sagittal angle becomes greater. In other word, the rotation axis of mandible should be located close to the occlusal plane at the ending of closing movement. In this study, the average of z-coordinate value of the LMAPs was approximately −0.6±7.12 mm. This result supports our hypothesis that the LMA could be located nearby the upper occlusal plane. Moss14) suggested that the area of the mandibular foramen remained relatively stationary during mandibular movements to avoid that the inferior alveolar neurovascular bundle would be endangered during the motion of the joint. Zhou et al.16) reported that the occlusal plane passed through the mandibular foramen region. The above would suggested the LMA could be used as a posterior functional landmark for anatomically and kinematically determining the occlusal plane.

2) Closing sagittal angle relative to the occlusal plane and IN-LMA plane

The location of occlusal plane is related to the occlusal bite force.6,10) The occlusal bite forces exert over time while occlusal contact occurs during mandibular closure. The inclination of the occlusal plane has a significant correlation with the direction of the closing path.11) Therefore, we
analyzed the closing path in this study. The \( \text{CA}\text{OCC} \) and the \( \text{CA}\text{LMA} \) of both the incisal path and the molar path were approximately 80 degrees. These values were smaller than the closing sagittal angle (87.9±9.4 degrees at 5 mm incisal closing level) reported by Ogawa et al.\(^\text{11}\). They used the lower occlusal plane as the reference plane and analyzed closing path during gum chewing. The curvature and inclination of occlusal plane is different between the upper and lower jaws\(^\text{22}\). We considered that this morphologic difference in the upper and lower dentition and the difference in the analyzed jaw motion data influenced the closing angle. There was no significant difference between the \( \text{CA}\text{OCC} \) and the \( \text{CA}\text{LMA} \). In addition, there was extremely strong correlation between the \( \text{CA}\text{OCC} \) and the \( \text{CA}\text{LMA} \), the slope of the regression line was very close to unity. The above results probe that the IN-LMA plane nearly corresponded with the upper occlusal plane. If the mandibular foramen locates at near level of the occlusal plane\(^\text{23}\), it was considered that the method using LMA for determining the occlusal plane is an appropriate means anatomically and functionally, into our study limitation.

3) Future work

In this current study, we investigate the relationship between the occlusal plane and the LMA, kinematically determined, in asymptomatic subjects. Further studies are needed in order to investigate the availability of the method using the LMA in symptomatic patients with functional and structural disturbances of the masticatory system, and the influence of the gender differences on its availability. To reveal the above future issues will lead to development a quantitative method for determining the occlusal plane.

V. Conclusion

In this present study, to investigate the relationship between the occlusal plane and LMA, the \( \text{CA}\text{OCC} \) and the \( \text{CA}\text{LMA} \) were calculated and evaluated. The \( \text{CA}\text{OCC} \) and the \( \text{CA}\text{LMA} \) were approximately 80 degrees, and there was no significant difference between them. Further, there was an extremely strong correlation between them. Consequently, the IN-LMA plane nearly corresponded with the upper occlusal plane.

From these results, it was considered that the method using LMA for quantitatively determining the occlusal plane is an appropriate means anatomically and functionally.

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