European Journal of Orthodontics 29 (2007) 21–25
doi:10.1093/ejo/cjl036
Advance Access publication 5 September 2006

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

Motonori Sato*, Mitsuru Motoyoshi*,**, Masayuki Hirabayashi***, Kouhei Hosoi*, Narihiro Mitsui* and Noriyoshi Shimizu*,**
*Department of Orthodontics and **Division of Clinical Research, Nihon University School of Dentistry and ***Private Office, Tokyo, Japan

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 ± 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 Salentijin, 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.*

(2000). 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.

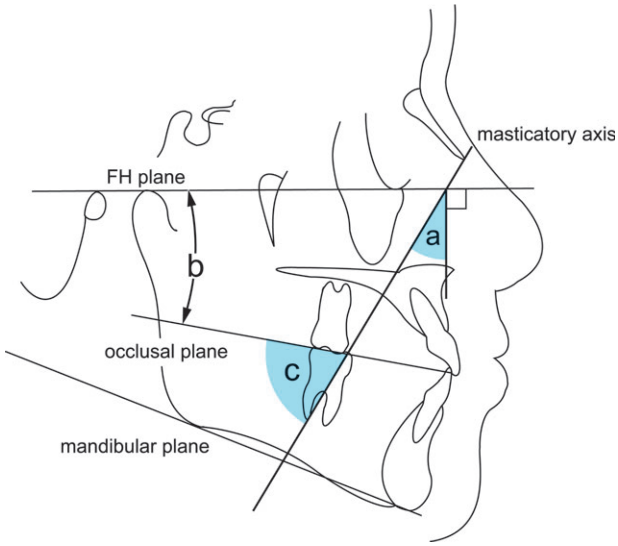

Figure 2 Definition of the masticatory axis. FH-masticatory angle (a), FH-Occ (b), the angle of the masticatory axis to the occlusal plane (c).

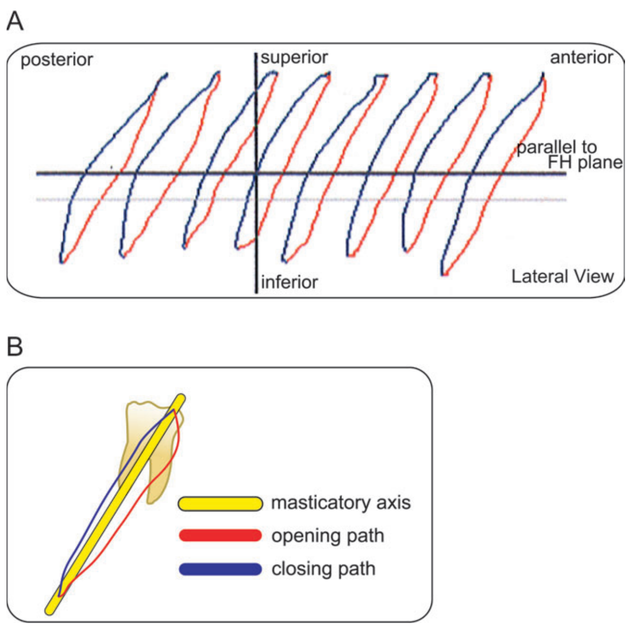

Figure 1 The masticatory path of the lower first molar (A). Definition of the masticatory axis (B).

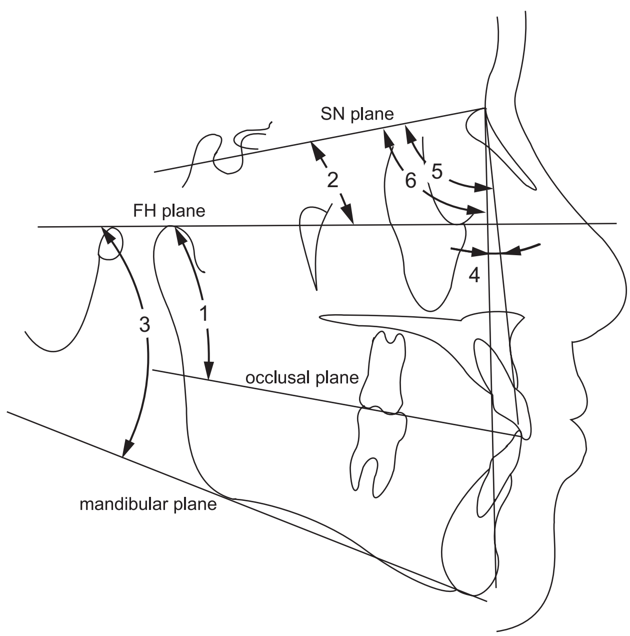

Figure 3 Cephalometric measurements—1, FH-Occ; 2, FH-SN; 3, FH-Mand; 4, ANB; 5, SNA; and 6, SNB.

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).

n = 17	FH-masticatory angle	Occ-masticatory angle	FH-Occ	FH-SN	FH-Mand	ANB	SNA	SNB
Minimum	18.0	61.3	0.5	4.5	14.5	−1.5	74.5	71.5
Maximum	39.9	75.0	14.5	13.5	36.0	7.0	84.5	85.0
Mean	27.7	69.1	6.79	9.06	25.00	2.29	80.4	78.1
SD	5.77	4.20	4.08	3.05	7.42	2.20	2.54	3.32

Table 2 Pearson's correlation coefficient between the FH-masticatory angle and cephalometric measurements.

	FH-Occ	FH-SN	FH-Mand	ANB	SNA	SNB
FH-masticatory angle	0.687**	−0.330	0.489*	0.300	0.353	0.071

*$P < 0.05$, **$P < 0.01$.

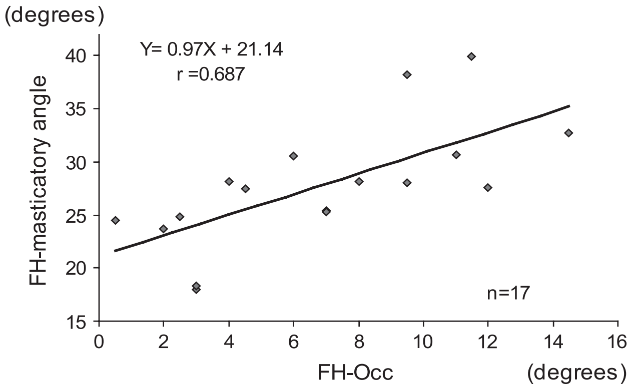

Figure 4 The relationship between the inclination of the occlusal plane and the masticatory axis.

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.

Address for correspondence

Motonori Sato
Department of Orthodontics
Nihon University School of Dentistry
1-8-13, Kanda Surugadai
Chiyoda-ku
Tokyo 101-8310
Japan
E-mail: sato-mt@dent.nihon-u.ac.jp

Acknowledgements

This study was supported by a grant from the Ministry of Education, Culture, Sports, Science, and Technology.

References

Appenteng K, Lund J P, Seguin J J 1982 Intraoral mechanoreceptor activity during jaw movement in the anesthetized rabbit. Journal of Neurophysiology 48: 27–37

Beata D, Andrzej M, Maciej R 2003 Finite element analysis of stress in molars during clenching and mastication. Journal of Prosthetic Dentistry 90: 591–597

Bilt A, Glas H W, Olthoff L W, Bosman F 1991 The effect of particle size reduction on the jaw gape in human mastication. Journal of Dental Research 70: 931–937

Daet D G, Watanabe M, Sasaki K 1995 Association between the interarch distance and food bolus size in the early phase of mastication. Journal of Prosthetic Dentistry 74: 367–372

DiPietro G J, Moergeli J R 1976 Significance of the Frankfort-mandibular plane angle to prosthodontics. Journal of Prosthetic Dentistry 36: 624–635

Gibbs C H, Lundeen H C (eds) 1982 Jaw movements and forces during chewing and swallowing and their clinical significance. In: Advances on occlusion. Wright, Boston, pp. 2–32

Gibbs C H, Lundeen H C, Mahan P E, Fujimoto J 1981 Chewing movements in relation to border movements at the first molar. Journal of Prosthetic Dentistry 46: 308–322

Hannnam A G 1991 The measurement of jaw motion. In: McNeill C (ed.) Current controversies in temporomandibular disorders. Quintessence Publishing Co., Chicago, pp. 130–137

Harvold E P 1963 Some biologic aspects of orthodontic treatment in the transitional dentition. American Journal of Orthodontics 49: 1–14

Hayasaki H, Saitoh I, Throckmorton G S, Iwase Y, Nakata S, Nakata M 2003 Occlusal phase of gum-chewing strokes. Journal of Oral Rehabilitation 30: 1041–1046

Huddleston Slater J J, Visscher C M, Lobbezoo F, Naeije M 1999 The intra-articular distance within the TMJ during free and loaded closing movements. Journal of Dental Research 78: 1815–1820

Inoue T, Kato T, Masuda Y, Nakamura T, Kawamura Y, Morimoto T 1989 Modifications of masticatory behavior after trigeminal deafferentation in the rabbit. Experimental Brain Research 74: 579–591

Korioth B 1990 Number and location of occlusal contacts in intercuspal position. Journal of Prosthetic Dentistry 64: 206–210

Lavigne G, Kim J S, Valiquette C, Lund J P 1987 Evidence that periodontal pressoreceptors provide positive feedback to jaw closing muscles during mastication. Journal of Neurophysiology 58: 342–358

Lund J P 1991 Mastication and its control by the brain stem. Critical Reviews in Oral Biology and Medicine 2: 33–64

Miyawaki S, Ohkochi N, Kawakami T, Sugimura M 2000 Effect of food size on the movement of the mandibular first molars and condyles during deliberate unilateral mastication in humans. Journal of Dental Research 79: 1525–1531

Moss M L 1981 Genetics, epigenetics, and causation. American Journal of Orthodontics 80: 366–375

Moss M L, Salentijin L 1969 The primary role of functional matrices in facial growth. American Journal of Orthodontics 55: 566–577

Naeije M 2003 Measurement of condylar motion: a plea for the use or the condylar kinematic center. Journal of Oral Rehabilitation 30: 225–230

Naeije M, Hofman N 2003 Biomechanics of the human temporomandibular joint during chewing. Journal of Dental Research 82: 528–531

Nakamura Y, Katakura N 1995 Generation of masticatory rhythm in the brainstem. Neuroscience Research 23: 1–19

Ogawa T, Koyano K, Suetsugu T 1998a Correlation between inclination of occlusal plane and masticatory movement. Journal of Dentistry 26: 105–112

Ogawa T, Koyano K, Umemoto G 1998b Inclination of the occlusal plane and occlusal guidance as contributing factors in mastication. Journal of Dentistry 26: 641–647

Ottenhoff F A, Bilt A, Glas H W, Bosman F 1993 Control of human jaw elevator muscle activity during simulated chewing with varying bolus size. Experimental Brain Research 96: 501–512

Palla S, Krebs M, Gallo L M 1997 Jaw tracking and temporomandibular joint animation. In: McNeill C (ed.) Science and practice of occlusion. Quintessence Publishing Co., Chicago, pp. 365–378

Proctor A D, DeVincezon J P 1970 Masseter muscle position relative to dentofacial form. The Angle Orthodontist 40: 37–44

Ramfjord S, Ash M M (eds) 1983 Neural and structural basis of motor behavior. In: Occlusion. W B Saunders, Philadelphia, pp. 71–127

Sassouni V 1969 A classification of skeletal facial type. American Journal of Orthodontics 55: 109–123

Sassouni V, Nanda S 1964 Analysis of dentofacial vertical proportions. American Journal of Orthodontics 50: 801–823

Slagter A P, Bosman F, Glas H W, Bilt A 1993 Human jaw-elevator muscle activity and food comminution in the dentate and edentulous state. Archives of Oral Biology 38: 195–205

Tokiwa H 2001 Evaluation of the clinical accuracy of an optical recording system for mandibular movement. Journal of Japanese Society of Stomatognathic Function 7: 13–25

Tokiwa H, Miura F, Kuwahara Y, Wakimoto Y, Twuruta M 1996 Development of a new analyzing system for stomatognathic functions. Journal of Japanese Society of Stomatognathic Function 3: 11–24

Yamamura C, Shimada K 1993 Differential controls of small and large motor unit activity in the masseter muscle with incisal stimulation in humans. Brain Research 632: 339–341

Yatabe M, Zwijnenburg A, Megens C C, Naeije M 1995 The kinematic center: a reference for condylar movements. Journal of Dental Research 74: 1644–1648

Yatabe M, Zwijnenburg A, Megens C C, Naeije M 1997 Movements of the mandibular condyle kinematic center during jaw opening and closing. Journal of Dental Research 76: 714–719