

Correlation between facial morphology, mouth opening ability, and condylar movement during opening–closing jaw movements in female adults with normal occlusion

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SUMMARY The aim of this study was to investigate the relationship between parameters of facial morphology, maximal voluntary mouth opening ability, and condylar movements in 21 adult females, aged between 20 and 24 years. The subjects had a normal occlusion without sign or symptoms of temporomandibular joint (TMJ) dysfunction. Mandibular movements were recorded using an opto-electric jaw movement recording system with six degrees of freedom under a series of maximal mouth opening–closing movements. Maximal jaw opening and coincident condylar movement were measured three-dimensionally. The mean values of the incisor and condylar path were 41.1 ± 3.5 mm (range 35.6–50.9 mm) and 12.8 ± 2.8 mm (range 8.1–19.2 mm), respectively. Although the positive correlation between maximal jaw opening and facial morphology was significant, none of the variables significantly differed between the value of the condylar path and facial morphology. The length of the path of maximum incisor movement and the condylar path during mandibular movement also did not correlate. Stepwise multiple regression analysis indicated a positive association between the maximal length of the incisor path and the cephalometric value of mandibular ramus inclination (R^2 value was 0.369). The results of this study suggest that facial morphology size has a limited effect on maximal voluntary mandibular opening and condylar movements in normal adult female subjects.

Introduction

Jaw opening capacity is regarded as one of the important parameters with which to evaluate the function of the temporomandibular joint (TMJ) and masticatory muscle status (Westling and Helkimo, 1992; Miller *et al.*, 1999). The linear length of maximal mandibular movement is regularly measured during clinical surveys of stomatognathic function. Many studies have focused on measuring the upper and lower inter incisor distance and condylar movements during habitual opening and closing jaw movement. Although Rieder (1978) found no direct connection between maximum jaw opening and a history of TMJ symptoms, Hesse *et al.* (1996) reported that maximum voluntary mouth opening was reduced in patients with TMJ problems

and Visser *et al.* (1995) also suggested a relationship between the opening capability of the mandible and the function of the masticatory muscles. An excessive or reduced range of mandibular movement could indicate signs and symptoms of muscular and/or TMJ dysfunction (Miller *et al.*, 1999).

In previous studies mandibular movement was directly measured between the incisal edge of the maxillary and mandibular central incisor using a device such as a Boley gauge. Recent technology for recording mandibular movement has been improved and comprehensive instrumentation with which to analyse stomatognathic functions that includes a mandibular movement recording system with six degrees of freedom has been developed. This system can reconstruct the path of any point on the mandible using a

mathematical rule and the mandibular movements of patients with TMJ problems using this system have been recorded (Tokiwa *et al.*, 1996; Tokiwa, 2001). To identify TMJ and to correctly diagnose temporomandibular dysfunction (TMD), useful parameters from the data obtained from TMJ patients and healthy subjects need to be established. Since the mobility of mouth opening is a useful parameter with which to distinguish the function of mandibular movement, data from normal adult subjects have been accumulated. These data include the linear length of the lower incisor and condylar paths, and velocity changes during various types of jaw movement (Hiromatsu *et al.*, 1998).

Ingervall (1971) suggested a correlation between jaw movement and facial morphology in young adults. He explained that variations in the range of jaw opening were due to differences in facial morphology. Landtwing (1978), following an examination of 1050 young people (468 girls and 582 boys) between 5 and 19 years of age, concluded that the capacity of mouth opening significantly depended on age and stature. Muto and Kanazawa (1996) found a correlation between maximal mouth opening and body height, mandibular length, and mandibular angle. They further reported the correlation between maximal mouth opening and movement of the condyle.

If the results of previous investigations for recording movement are correct, each subject should be selected and classified based upon facial morphology. The aim of this study was to investigate the effect of the size of facial morphology on maximal jaw opening and condylar movements in normal adult female subjects. Measurement variables of facial morphology obtained from lateral head radiographs and recorded data of the incisor and condylar paths during mandibular movement were analysed using multiple regression analysis.

Subjects and methods

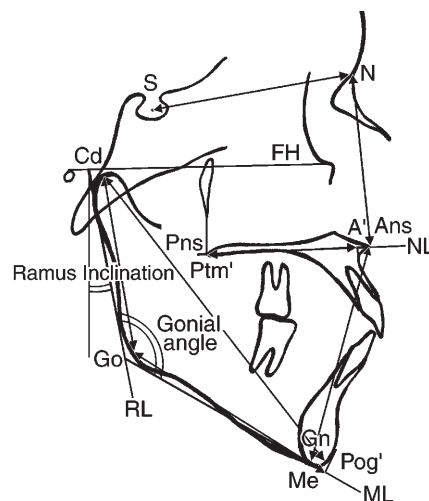
Subjects

Twenty-one healthy female subjects aged between 20 and 24 years (mean 22 years) with normal occlusion were selected from students

at the Tsurumi University School of Dental Medicine following a dental examination by one of the authors. None had undergone orthodontic treatment before the examination, or showed signs or symptoms of craniomandibular disorders, and all subjects had a normal occlusion. The aim and protocol of this study was explained to all participants prior to the start of recording. All subjects provided written informed consent to participate. This study was approved by the Ethical Committee of Tsurumi University, School of Dental Medicine.

Cephalometric analysis

Lateral cephalograms obtained with the teeth in maximum intercuspation were traced on acetate paper by one author and checked by another before facial morphology was measured. All cephalograms were standardized and all measurements adjusted for magnification. The reference points and lines used are given in Figure 1 and Table 1. Angular and linear cephalometric variables are listed in Table 2. Cephalometric analysis was incorporated into a personal computer by a digitizer (CephaloMetrics A to Z ver. 2.6, Yasunaga Computer system, Japan). Overbite and overjet were measured on dental casts taken from each subject.



$$\text{Ramus Inclination} = 90^\circ - \angle(\text{FH to Cd-Go})$$

Figure 1 Cephalometric reference points and measurement values.

Table 1 Reference points and planes used in the cephalometric analysis.

	Definition
Points	
S = sella	The mid-point of sella turcica
N = nasion	The extreme anterior point on the frontonasal suture
Cd = condylion	The extreme superior point of the condyle
Gn = gnathion	The mid-point between pogonion and menton
Go = gonion	The intersection between the external contour of the mandible and the bisector of the angle between the RL and the ML lines
ANS = anterior nasal spine	The extreme anterior point on the maxilla
PNS = posterior nasal spine	The extreme posterior point on the maxilla
Me = menton	The most inferior point on the mandibular symphysis
A' = point A	Perpendicular to the nasal line
Point A	The deepest point in the curvature of the maxillary alveolar the process
Ptm'	A point perpendicular to the nasal line
Point Ptm	The extreme inferior point of the pterygopalatine fossa
Pog'	A point perpendicular to ML
Point Pog	The most anterior point on the frontonasal suture
Planes	
S-N	Sella-nasion line
FH	Frankfort horizontal plane, the line through orbitale and porion
NL	Nasal line, the line through Ans and Pns
RL	Ramus line, the tangent to the mandibular ramus through articulare
ML	Mandibular line, the tangent to through to the lower border of the mandible through menton

Table 2 Angular and linear variables used in the cephalometric analysis.

	Definition
Cranial base	
S-N	Anterior cranial base length (mm)
N-ANS	Upper anterior face height (mm)
ANS-Me	Lower anterior face height (mm)
Maxillary dimensions	
A'-Ptm'	Maxillary length (mm)
Mandibular dimensions	
Gn-Cd	Total mandibular length (mm)
Go-Pog'	Corpus length (mm)
Cd-Go	Ramus length (mm)
Gonial angle	Angle between RL and ML (degree)
Ramus inclination	Complementary angle between RL and FH (degree)

Mandibular movement recording and analysis

Mandibular movement was recorded using a specific instrumentation (Gnathohexagraph, JM-1000, Ono Sokki, Japan) with six degrees of freedom at a sampling frequency of 90 Hz. The system consists of two CCD cameras, a set of head frames and a mandibular facebow unit containing LED markers and a stereo imaging

processing system compatible with Windows version 3.1 to reconstruct mandibular movement (Figure 2; Tokiwa *et al.*, 1996).

The mandibular facebow unit was rigidly attached to a clutch that was mounted on the mandibular incisors before measurement (Figure 3). The clutch was carefully formed and placed on the anterior teeth of the lower dental arch with dental resin and cyanoacrylate adhesive

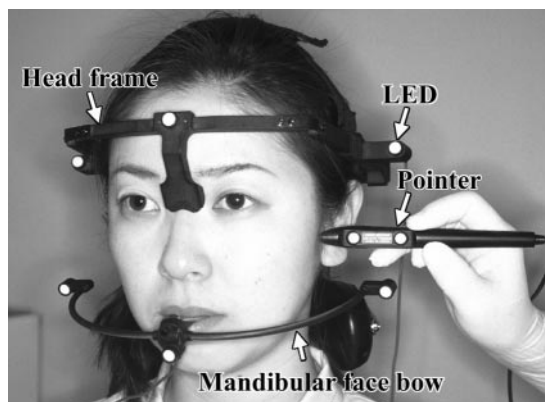


Figure 2 Head frame and mandibular facebow units with LED markers attached to the subject. Points of registration were recorded with a LED pointer.

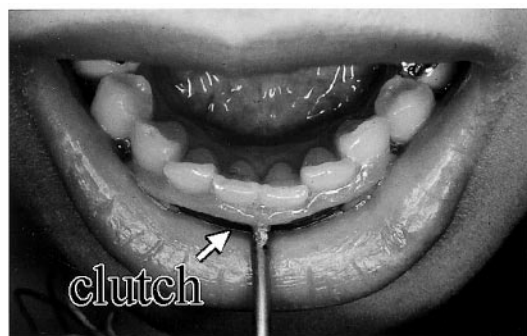


Figure 3 The clutch was rigidly mounted on the mandibular incisors and attached to the mandibular facebow.

to minimize interference from lip sealing and jaw movements (Figure 3). The total weight of the mandibular facebow including the incisor clutch was approximately 12 g. Movement of the LED markers in the head frame was recorded as movement of the head by the CCD cameras, whereas movements of the LED markers in the mandible consisted of combined movements of the head and the mandible. Real movements of the mandible were obtained by subtracting the movement of the LED marker in the head frame from movement of the LED marker in the mandible. The formulae for rigid body mathematics were used to reconstruct the movement path of any point of the mandibular bone relative to the head (Tokiwa *et al.*, 1996).

The reference points, i.e. lower incisor point, porion, and orbitale, were registered by a LED reference pointer (Figure 2). The position of the anatomical condylar points was determined by palpation during opening and closing movements of the mouth. The condylar point was registered by a LED reference pointer attached on the skin surface of the condylar point. In this study the anatomical points of the condyle were used for analysis. The accuracy of the registered reference points has previously been confirmed (Tokiwa, 2001).

The head frame and mandibular facebow units were attached to the subject whilst sitting upright in a dental chair. The head was unrestrained. During recording they were instructed to open and close their mouth quickly and widely as comfortably as possible in a habitual manner. Movement was recorded for 30 seconds during which no pain was reported by the subjects. Maximum jaw opening and condylar movement were determined by three-dimensional linear measurements (Figure 4) and analysed by selecting the paths of maximum incisor and condylar movements during a series from the fifth to tenth of maximum mouth opening cycles.

Statistical analysis

The data were statistically analysed using the SPSS package (Ver.10.0 for Windows). Means and standard deviations were computed for each independent variable. The mean values of the

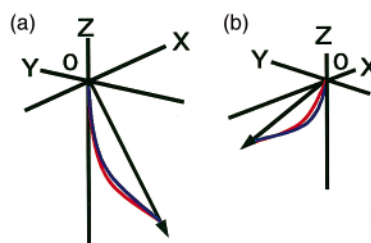


Figure 4 Three-dimensional linear measurements of incisor (a) and condylar paths (b). Red line shows opening phase, blue line indicates closing phase. 0, point of centric occlusion; X axis, horizontal plane; Y axis, frontal plane; Z axis, sagittal plane.

facial morphology of the subjects were compared with Japanese standards for adult females (Nagaoka and Kuwahara, 1993). Differences in mean values were assessed by Student's *t*-test. The correlation coefficient of the relationship between craniofacial dimensions, and maximum jaw and condylar movements was evaluated. A stepwise multiple regression analysis determined the relationship between jaw movement and facial morphological parameters. The level of significance was set at $P < 0.05$.

The error of the method was assessed using replicate tracings and measurements on all films with the method error values calculated using a paired *t*-test. No systematic differences were found between the original and replicate measurements (Houston, 1983).

Results

The results of the comparison of the cephalometric values of the subjects and Japanese standards for an adult female are shown in Table 3. None of the variables between the subjects and Japanese standards differed significantly.

Figure 5 shows examples of typical incisor and condylar paths. The mean values of the lengths of the incisor and condylar paths during maximum jaw opening are given in Table 4. Table 5 shows Pearson's correlation coefficients between the craniofacial variables and the maximum length of the incisor and condylar

paths during jaw movement. Although many of the correlations between incisor path and facial morphology were significant, none of the variables for the values of the condylar path and facial morphology differed significantly. While maximum incisor movement was positively correlated with ramus inclination, gonial angle, maxillary length (A'-Ptm'), and anterior cranial base length (S-N), no correlation was evident between incisor and condylar movements.

The results of the stepwise multiple regression analysis are shown in Table 6. The maximum length of the incisor path was associated with the variable, ramus inclination of the mandible (R^2 value = 0.369). The maximum condylar path was not associated with the variable of ramus inclination of the mandible and/or gonial angle (R^2 value = 0.00).

The method error did not detect a difference between the original and replicated measurements at the 5 per cent level of significance ($t = 1.949$, $P > 0.05$).

Discussion

In previous studies, methods for measuring the mandibular movement were varied. Although most investigators directly measured the length of maximum mouth opening using a Boley gauge (Seno *et al.*, 1997; Miller *et al.*, 1999) or a plastic ruler (Ingervall, 1970a,b; Agerberg, 1974a,b; Visser *et al.*, 1995; Muto and Kanazawa, 1996), a

Table 3 Descriptive statistics of cephalometric measurements ($n = 21$).

	Mean	SD	Range	Japanese standards (mean \pm SD)
Cranial base				
S-N (mm)	69.9	3.0	64.3-75.9	68.69 \pm 2.82
N-ANS (mm)	57.1	2.7	52.1-62.6	57.33 \pm 3.04
ANS-Me (mm)	72.2	5.5	56.3-62.6	70.08 \pm 4.38
Maxillary dimensions				
A'-Ptm' (mm)	49.9	2.8	43.4-55.7	50.13 \pm 3.22
Mandibular dimensions				
Gn-Cd (mm)	121.9	5.7	105.7-130.8	120.83 \pm 5.21
Cd-Go (mm)	61.2	4.5	51.7-69.4	61.16 \pm 4.31
Pog'-Go (mm)	79.9	3.9	73.5-89.1	79.99 \pm 4.66
Gonial angle (degree)	123.2	7.5	109.8-136.1	121.62 \pm 5.96
Ramus inclination (degree)	5.0	4.8	-3.2-12.8	4.54 \pm 5.18

Japanese standards are from Nagaoka *et al.* (1993). For abbreviations see Table 2.

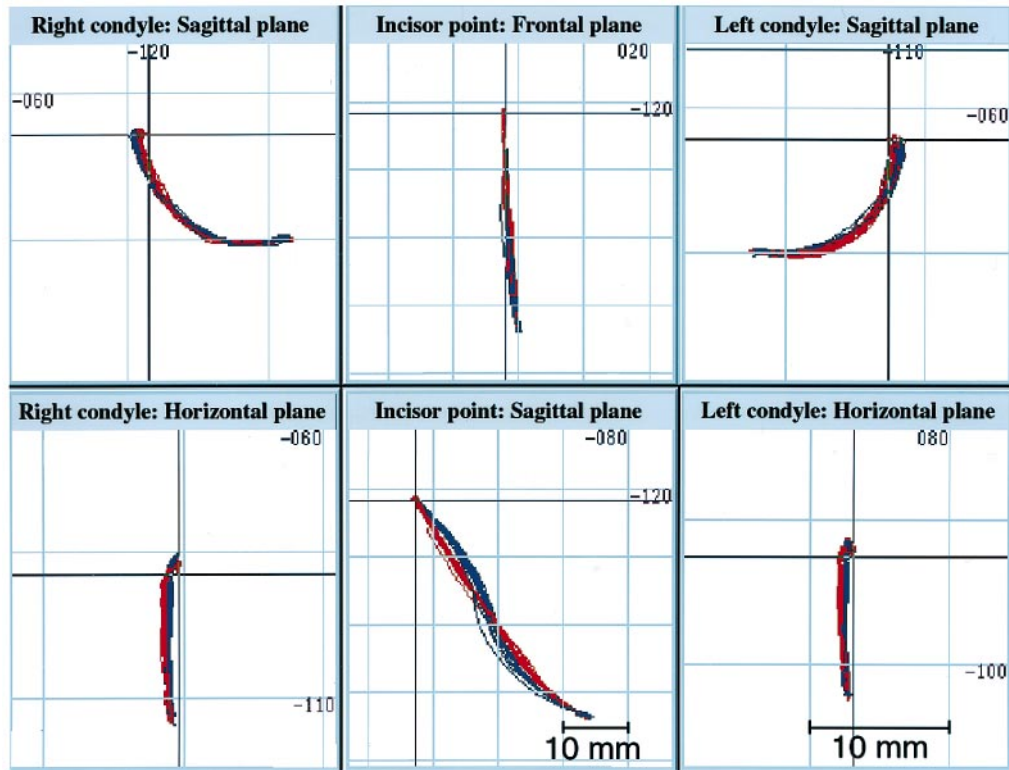


Figure 5 Typical movements of incisor and condylar points during five maximum opening and closing cycles. These movement paths showed a smooth and convex line without abrupt directional changes. Red line opening phase, blue line closing phase. Bar = 10 mm length.

Table 4 Three-dimensional linear measurements of maximum jaw and condylar movements (mm).

	Mean	SD	Range
Maximum jaw movement	41.1	3.5	35.6–50.9
Maximum condylar movement	12.8	2.8	8.1–19.2

few (Hesse and Naeije, 1990; Chen, 1997; Travers *et al.*, 2000) recorded the maximum border length of jaw opening using recording instruments. McCarroll *et al.* (1987), Hesse and Naeije (1990), and Westling and Helkimo (1992) adopted two types of measurement, namely active and passive ranges of mandibular opening capacity. While the active range of movement of the mandible denotes that a person is voluntarily opening the mouth, the passive range means

that the examiner physically opens the relaxed jaw of a subject. McCarroll *et al.* (1987) referred to the difference between the active and passive border positions as the 'end-feel' distance. According to Hesse and Naeije (1990), the mean value of the 'end-feel' distance measured by an opto-electric device is 3 mm in healthy female dental students.

Few investigators have used mechanical or opto-electrical instrumentation to record mandibular movement (Hesse and Naeije, 1990; Chen, 1997; Travers *et al.*, 2000). The present study used an opto-electric system for measuring the mandibular movements with six degrees of freedom. Before collecting data on the mandibular movement, the size or morphology of the facial bones of all subjects was measured using cephalograms. Table 3 shows the mean and range of the cephalometric values of the subjects

Table 5 Correlations among maximum jaw movement (MJM) and condylar movement (CM) and craniofacial dimensions.

	MJM	CM	N-S	N-ANS	ANS-Me	A'-Ptm'	Gn-Cd	Cd-Go	Pog'-Go	Go angle
MJM										
CM	0.081									
S-N	0.446*	-0.018								
N-ANS	-0.206	0.280	0.006							
ANS-Me	0.324	-0.173	0.522**	0.121						
A'-Ptm'	0.525*	0.056	0.473*	-0.170	-0.061					
Gn-Cd	0.281	0.002	0.573**	0.167	0.775	0.238				
Cd-Go	-0.234	0.229	0.085	0.158	0.153	0.320	0.496*			
Pog'-Go	0.069	-0.092	0.319	0.453*	0.448*	0.110	0.743**	0.444		
Go angle	0.592*	-0.012	0.511*	-0.260	0.449*	0.354	0.321	-0.479*	-0.138	
Ramus Inc.	0.634**	0.110	0.411	0.449*	0.167	0.517*	0.359	-0.070	-0.045	0.748**

Correlation coefficient differs significantly from zero at * $P < 0.05$, ** $P < 0.01$.

Table 6 Stepwise multiple regression analysis.

Independent variable	Standard regression coefficient	F value
Maximum jaw movement		
Ramus inclination	0.630	12.10
R^2 value = 0.369		
F value = 12.102 ($P < 0.01$)		
Condylar movement		
Ramus inclination	0.160	0.566
Gonial angle	-0.080	0.355
R^2 value = 0.000		
F value = 0.284 (NS)		

and the norms for Japanese adult females (Nagaoka and Kuwahara, 1993). The cephalometric values of the subjects in this study were not significantly different from the Japanese standard, which confirmed that the subjects had a normal facial morphology. Dental examination confirmed that all subjects had no facial abnormalities or TMD.

Mandibular movement was recorded during a series of maximum voluntary mouth opening and closing movements for 30 seconds. Forced and voluntary modes of mandibular movement are quite different. Similarly, the nature of a single movement or a serial movement of the mandible is also quite different. The weight of the device attached to the mouth of the subject in this study was 12 g, which was somewhat

lighter than that in other measuring methods. The parameters obtained in this study indicate the natural and/or normal physiological conditions of mandibular movement even if the weight of the mandibular facebow and clutch influenced jaw movement (Figure 2).

Table 4 shows the results of linear measurements of incisor and condylar paths. The parameter of the incisor path, which indicates the distance between the upper and lower incisal edge during maximum jaw opening, has been measured by several investigators. These values in female subjects ranged between 45 and 54 mm: Nevakari (1960), 54.0 mm; Ingervall (1970a), 51.29 mm; Agerberg (1974b), 53.3 mm; Solberg *et al.* (1979), 50.9 mm; Takenoshita *et al.* (1983), 43.36 mm; Hesse and Naeije (1990), 53.6 mm; Westling and Helkimo (1992), 53.8 mm; Visser *et al.* (1995), 52.0 mm; Muto and Kanazawa (1996), 46.9 mm; Seno *et al.* (1997), 44.8 mm; and Tsukahara *et al.* (1998), 51.1 mm. The variations among these values might be due to differences among the samples and measurement methods. The parameters obtained in the present study indicated smaller values than those of previous reports. The mean values of Japanese female subjects seem to be smaller than those of Caucasian female subjects (Muto and Kanazawa, 1996; Seno *et al.*, 1997; Tsukahara *et al.*, 1998). According to a survey, the average height of a Japanese female (mean age 17 years) is 158 cm (Ministry of Education, Culture, Sports, Science

and Technology, 1997), which is smaller than the average values for Caucasian females (Agerberg, 1974b). Although some studies have concluded that height influences the parameters of mandibular movement (Ingervall, 1970b; Agerberg, 1974a; Pullinger *et al.*, 1987; Chen, 1997), others have not found a correlation between height and the kinematic parameters of the mandible (Ingervall, 1971; Pullinger *et al.*, 1987; Westling and Helkimo, 1992; Muto and Kanazawa, 1996). Ingervall (1970a, 1971) studied the range of mandibular movements in children (7–10 years old) and young female adults (20 years old). He found that the opening capacity in children was positively correlated with height and weight, whereas that in young female adults did not correlate with height and weight (Agerberg, 1974b). Since the height of the subjects in the present investigation was not measured, its relationship to parameters of mandibular movement cannot be discussed. The body height of the subjects might influence the value of the parameters.

Ingervall (1971) was the first to investigate the effect of facial morphology on maximum jaw opening in young female adults. He adopted a stepwise linear regression analysis as the statistical method and reported correlation and multiple correlation coefficients. He concluded that the maximum length of mouth opening varies with the inclination of the ramus ($r = -0.31$), the length of the mandible ($r = 0.21$), and the length of the anterior cranial base ($r = 0.22$). He reported that the angle between the posterior cranial base and the mandibular ramus was the most significant morphological variable. Opening capacity was positively correlated with cranial base and mandibular length, which were significantly negatively correlated with sagittal jaw relationship, and the inclination of the mandibular base line. He concluded that 25–40 per cent of the inter-individual variations in the range of movement could be explained by inter-individual variations in facial morphology with the angle between the posterior cranial base and mandibular ramus being the most important morphological variable.

To define useful parameters from recorded data, statistical methods have been applied to

numerous variables. In this study, the correlation between the parameters of jaw movement and craniofacial dimensions were calculated using a stepwise linear regression analysis. The craniofacial variables, i.e. S–N, A'–Ptm', ramus inclination, and gonial angle, were significantly correlated with the ability to open the mouth. Stepwise linear regression analysis confirmed ramus inclination as the significant independent variable for mouth opening capacity. These results are in agreement with those of Ingervall (1971) except for the mandibular length variable. The more the angle of ramus inclination increases, the more the mandible rotates in an anti-clockwise direction. Thus, the capability of mouth opening is influenced by mandibular ramus inclination.

Data on the condylar movement path of normal adult subjects during voluntary opening and closing mandibular movement have been reported previously (Hiromatsu *et al.*, 1998; Travers *et al.*, 2000). Movement of the condyles was also recorded and analysed in the present study. The mean value of the length of the condylar path was 12.8 mm. Few investigators have measured the condylar movement path, since appropriate recording instrumentation has been unavailable. Among such studies, Chen (1997) measured the length of condylar paths in 25 normal adult male and female subjects using the same type of opto-electrical instrumentation as the present investigation. The mean value of the condylar path was 14.16 mm, which represented the mean of both sexes. Muto and Kanazawa (1996) measured cephalograms in adult subjects and found that the direct lengths of the condylar points between central occlusal and maximum jaw opening positions in male and female were 20.5 and 18.1 mm, respectively. Zhang *et al.* (1998) observed the movement of the condyle by videofluorography in TMD subjects. The mean value of condylar movement was 12.8 mm at a superior disc position. Recently, Travers *et al.* (2000) reported that the condyles moved average straight line distances of 11.9 and 12.2 mm during opening and closing, respectively. The measurement result in this study was reasonable compared with other reports. Although only healthy female adult

subjects were examined, those with malfunctions of the TMJ should also be investigated.

Examining the relationship between the length of the condylar path and facial morphology, no significant correlation between condylar movement and all variables was found. Although the other investigators found a correlation between maximal mouth opening and condylar movement, the lengths of the condylar and incisor paths were not correlated in the present study (Dijkstra *et al.*, 1995; Muto and Kanazawa, 1996). The reason for the difference in results on the movement of the condyle is unclear. Since movement of the condyle is composed of rotation and translation during mouth opening, the direct measurement of the condylar path may be difficult to investigate. Thus, both rotation and translation movements must be analysed separately during opening and closing movements. Only this result suggests that the rotation factor of condylar movement might influence a major part of mandibular movement. Future studies should elucidate the complex mechanism of condylar movements.

Conclusions

Twenty-one normal female adult subjects were investigated regarding the ability to maximally open the jaw, and correlations sought for condylar movements and the size of the facial morphology. The results suggest that facial morphological size has little influence on maximum voluntary mandibular opening and condylar movements. As a clinical consequence, the facial morphology or facial type of the patient might be mentioned to determine the parameters related to the ability of jaw movement.

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