Medial Mandibular Flexure and Maximum Occlusal Force in Dentate Adults

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Purpose: Medial mandibular flexure (MMF) is the functional narrowing of the mandible during opening and protrusion movements, which may affect conventional or implant-supported prostheses. This study evaluated the association among MMF, maximum occlusal force (MOF), gender, weight, height, body mass index (BMI), and age in 80 dentate adult subjects (40 women, 40 men; age range 20 to 38 years). **Materials and Methods:** Bilateral MOF was measured using a cross-arch force transducer placed in the first molar region. For MMF calculation, impressions of the mandibular occlusal surface were made with vinyl polysiloxane putty material in rest (R), maximum opening (O), and maximum protrusion (P). The impressions were scanned, and the images were processed using Adobe Photoshop software. Reference points were selected on the occlusal surface of the contralateral first molars, and the linear intermolar distance was measured using Image Tool software. MMF was calculated by subtracting the intermolar distance during opening or protrusion from the intermolar distance during rest. **Results:** Mean values of MOF were 698.14 N for women and 1,009.48 N for men; MMF-O was 0.146 mm and MMF-P was 0.15 mm for the total sample. No correlation was found between MOF and MMF (r = 0.02 for MMF-O; r = 0.11 for MMF-P; P > .05) or between MMF and weight, height, BMI, or age. MOF was significantly associated (P < .001) with weight (r = 0.509), height (r = 0.459), and BMI (r = 0.423), but not with age (r = 0.009). **Conclusion:** These results suggest that MMF is not associated with MOF in this sample of dentate adults. *Int J Prosthodont 2006;19:177–182.*

Medial mandibular flexure (MMF) is elastic deformation characterized by medial convergence of the hemimandibles during jaw opening and protrusion movements.[1] MMF occurs concurrently with other types of mandibular deformation[2,3] and may affect the clinical success of extensive bilateral prostheses in the mandible. Previous studies report that the relative position of teeth and implants in different jaw positions may lead to distortion of impressions and interocclusal recordings, as well as compromise the passive adaptation of prostheses and increase the risk for fracture of prosthetic components and luting agents.[1,4–8] For implant-supported prostheses, these problems would be greater because of the absence of the periodontal ligament, which may compensate flexure strain on natural teeth. Splitting the prosthesis suprastructure at midline (symphysis area) or into 3 segments (1 anterior and 2 posterior) has been proposed to prevent implant-supported prosthesis failure related to MMF.[5,6,8]

The determinants of MMF and their interaction still are not completely understood. Multiple factors, such as masticatory muscle action, skeletal pattern, and bone density,[1,9,10] might have different impacts on the magnitude of MMF. The muscular component is fun-

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The present report is based on a thesis submitted to the Pontifical Catholic University of Rio Grande do Sul in partial fulfillment of the requirements for the MSc degree. This study was presented at the 21st Annual Meeting of the Brazilian Division of the International Association for Dental Research (IADR), in Águas de Lindóia/SP, Brazil, September 8–12, 2004.

damental to MMF, because the muscles originating from or inserted into the mandible coordinate jaw movements. The activity of the lateral pterygoid, masseter, temporal, and medial pterygoid muscles has been related to MMF and other types of mandibular deformation.[9,11,12] Although some studies and anecdotal reports suggest that muscle strength influences mandibular distortion[4,5,10] no study in humans has tested the hypothesis that individuals with stronger masticatory muscles have larger MMF. Voluntary maximum occlusal force has been used as a measure of strength of the masticatory muscles; however, maximum occlusal force (MOF) presents large intersubject variability because of a number of variables, such as occlusal stability, age, gender, and height.[13–15]

This cross-sectional study sought to evaluate the relationship among MMF, voluntary MOF, and anthropometric measures (weight, height, and body mass index [BMI]) in a selected group of dentate adults.

Materials and Methods

A convenience sample of 87 volunteers was recruited from the students and faculty of the Pontifical Catholic University of Rio Grande do Sul Dental School. Preliminary sample size calculation yielded a minimum number of 62 subjects for correlation analysis ($r = 0.35$ different from zero), considering $\alpha = .05$ (two-tailed) and $\beta = .20$. Eligibility criteria included complete dentition (facultative presence of third molars), age range from 20 to 50 years old, and normal occlusion. Subjects were excluded if they had a history of maxillofacial surgery, mandibular trauma, or orthodontic treatment within the previous 2 years; for presence of active periodontal disease with tooth mobility, osseous or neuromuscular diseases, large facial skeletal alterations, or orofacial pain; or if they were pregnant. The research project was approved by the university's Institutional Review Board according to national and international standards for clinical research, and all participants signed an informed consent form.

Anthropometric measures were obtained from each volunteer during the initial clinical exam. Each subject's height was measured in centimeters with the subject in an erect position without shoes, and weight was recorded in kilograms using a mechanical anthropometric scale (Welmy, model R110). The BMI was calculated using the formula BMI = weight/height^2 (kg/m^2).

Voluntary MOF

Voluntary MOF was measured with a compressive load transducer (Sensotec13/2445-02) placed in the first molar region.[15] The bite pad containing the load transducer was covered with a hard rubber band to protect the teeth and equally distribute the occlusal force, and the set was wrapped with disposable plastic film for infection control. The interocclusal distance of the bite pad at the insertion point was 14 mm. The subjects received experimental instructions and training in biting the bite pad several times before the actual recorded trials. Each subject was then asked to bite the equipment 5 times with maximal effort for 1 to 2 seconds, with rest intervals between trials. The occlusal force was recorded in pounds and converted into newtons. The 3 highest measures were averaged and considered the subject's MOF value.

Medial Mandibular Flexure

MMF was measured by calculating the variation in the intermolar distance from rest to maximum opening (or maximum protrusion) positions using an impression technique modified from Sesma et al.[16] For each subject, impressions of the occlusal and incisal thirds of the mandibular teeth were obtained during relative rest (minimum mouth opening for impression making), maximum opening, and maximum protrusion. A customized metallic support similar to a bite fork of a semiadjustable articulator was used as a tray for the vinyl polysiloxane putty material (3M Express). Impressions were standardized with centric stops on bilateral canines and molars that were in contact with the metallic support.

With the measuring head set at a 10-mm width, the impressions and digital calipers (Mitutoyo Sul Americana Ltd) were scanned at 200% magnification and 300 dpi resolution using a desktop scanner. The positioning of the impression during scanning was standardized using a plastic support that kept the metallic tray and the impression plane parallel to the scanner surface. The digitized images were saved in JPEG format. Using Adobe Photoshop 4.0 software, each image was converted to grayscale, inverted, and adjusted for brightness and contrast to provide the best visualization of the occlusal surface. At 200% zoom, anatomic reference points on the contralateral first molars were selected for the 3 images (rest [R], opening [O], protrusion [P]) and marked with a 5-pixel red point. All 3 images for each subject (R, O, P) were processed simultaneously on the computer monitor and saved in JPEG format (Fig 1a).

The intermolar linear distance was measured with Image Tool software (University of Texas Health Science Center at San Antonio; this software can be downloaded at http://ddsdx.uthscsa.edu) with 2:1 magnification. Before the intermolar measurement was made, each image was calibrated with the digital calipers image (10-mm width). A line was traced between the outer borders of the 2 reference points on the con-

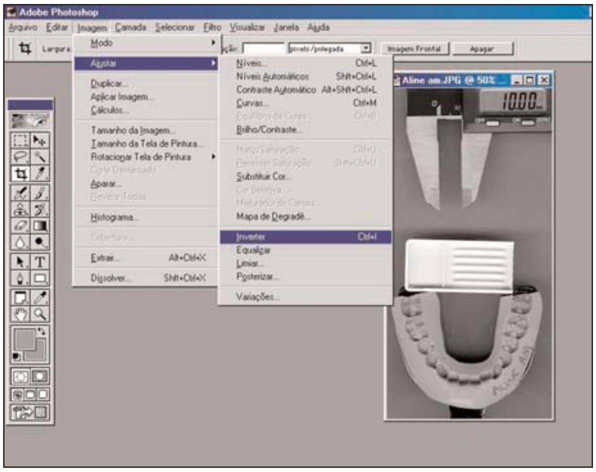

Fig 1a Images were processed with Adobe Photoshop 4.0 software. Inversion, grayscale conversion, adjustment of contrast and brightness, and selection of anatomic reference points on contralateral first molars were performed.

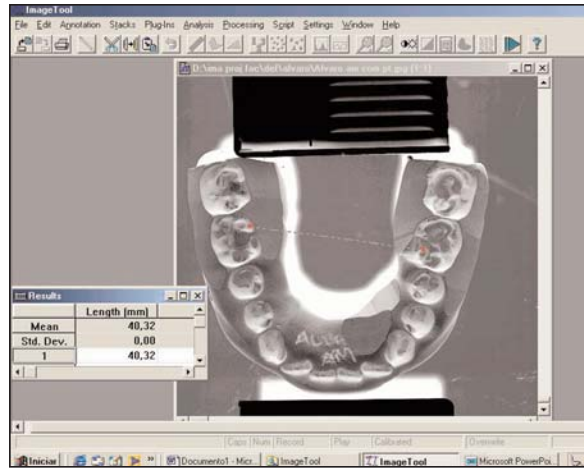

Fig 1b Measurement of the intermolar distance with ImageTool software.

tralateral first molars. The software calculated the intermolar distance in millimeters according to the previous calibration (Fig 1b). Sensitivity of the linear distance measurement was 0.01 mm. Intermolar distance was measured in triplicate for each image and averaged.

MMF during maximum opening (MMF-O) was calculated by subtracting the intermolar distance at O position from that at R position. MMF during maximum protrusion (MMF-P) was calculated in a similar way from the measurements in P and R positions. A single calibrated examiner, who was blinded to occlusal force values, performed all linear measurements and MMF calculations. Reliability tests of this method yielded intrarater intraclass correlation coefficients (ICCs) from 0.98 to 0.99 and interrater ICCs of 0.69.[17] To test the method for repeatability, we estimated test-retest reliabilities. Four occlusal mandibular impressions for each position (maximum opening, maximum protrusion, and rest) were taken from 4 persons on different days. After the image acquiring, processing, and measuring procedures, ICC was calculated for each person considering the linear measures for each position to assess consistency over time. ICCs ranged from 0.96 to 0.99, indicating high test-retest reliability.

Statistical Analysis

The main outcome measures were MMF (in millimeters) and MOF (in newtons), which presented normal distribution (Shapiro-Wilks test, .05 significance level).

Bivariate associations between MMF, MOF, age, gender, and anthropometric variables (weight, height, BMI) were tested using Pearson correlation tests. Comparisons between groups in relation to potential confounders for MMF (presence/absence of bruxism, presence/absence of tooth wear, presence/absence of muscular pain, or presence/absence of first mandibular premolar) were analyzed by Student t tests with Bonferroni correction. A P value of .05 (two-tailed) was considered statistically significant for rejection of the null hypothesis.

Results

Seven volunteers (4 men and 3 women) were excluded because of problems during data collection and image processing; therefore, the final sample size was 80. Descriptive characteristics of the sample ($n = 80$) are shown in Table 1. MMF was not significantly different between men and women for opening and protrusion movements. MOF was significantly higher for men than for women (Student t test; $P < .001$). Women also presented larger variability of MOF. The anthropometric values (weight, height, BMI) were higher for men.

MMF-O and MMF-P did not show significant association with MOF ($r = 0.020$, $P = .859$, and $r = 0.111$, $P = .327$, respectively). Also, there were no significant correlations between MMF and weight, height, BMI, age, or gender (Table 2). The scatterplot graphs of MMF versus MOF did not show any patterns or trends (Fig 2).

MOF was associated with weight ($r = 0.509$), height ($r = 0.459$), and BMI ($r = 0.423$) at the .01 significance level. Age did not have any significant correlation with the other variables. The analysis of potential confounders (presence/absence of bruxism, presence/absence of tooth wear, presence/absence of muscular pain, presence/absence of mandibular first premolar) did not demonstrate significant differences for MMF values in maximum opening and in maximum protrusion positions (Table 3).

Table 1 Demographic and Clinical Characteristics of the Sample (n = 80)

Variable	Frequency (%)	Mean* (SEM)	Minimum/ maximum
Gender			
Female	40 (50)		
Male	40 (50)		
Age (y)		25.30 (0.464)	20/38
Occlusal force (N)		838.81 (33.00)	312.85/1,886.63
Women		698.14 (28.38)[a]	312.85/1,045.32
Men		1009.48(45.98)[b]	581.97/1,886.63
MMF-O (mm)		0.146 (0.024)	–0.70/0.72
Women		0.174 (0.035)[a]	–0.31/0.72
Men		0.115 (0.032)[a]	–0.70/0.44
MMF-P (mm)		0.150 (0.027)	–0.53/1.08
Women		0.154 (0.037)[a]	–0.53/0.76
Men		0.146 (0.041)[a]	–0.42/1.08
Weight (kg)		66.48 (1.58)	46.00/123.50
Women		56.07 (0.89)	46.00/70.10
Men		76.88 (1.95)	61.00/123.50
Height (m)		1.71 (0.11)	1.52/1.92
Women		1.64 (0.01)	1.52/1.79
Men		1.78 (0.01)	1.63/1.92
BMI (kg/m^2)		22.45 (0.34)	16.72/36.24
Women		20.76 (0.27)	16.72/25.26
Men		21.45 (0.48)	20.19/36.24

*Means followed by distinct letters are statistically different (Student *t* test, $P < .001$).

Discussion

MMF during opening and protrusion movements has been related to contraction of the lateral pterygoid muscles, which pull the mandibular condyles medially.[18] The force generated by the masticatory muscles during jaw opening and protrusion is difficult to measure. MOF reflects the activity of the masticatory muscles with vertical components of the resulting contraction force, such as the masseter and temporal muscles. This is not the case with the lateral pterygoid muscle,[19] which is relatively weak.[10] Nevertheless, since masticatory muscles act in a complex synergy of coactivation, it is assumed that the lateral pterygoid muscle has power proportional to its size, similar to other masticatory muscles. Accordingly, this study investigated whether subjects with high MOF also have large MMF values, but the results from this sample did not support this hypothesis. The probability calculated for correlation tests was rather distant from the stipulated level of significance. Moreover, the bivariate correlation coefficients were very weak and would not be clinically relevant, even if they were statistically significant.

Table 2 Pearson Correlation Coefficients (*P* Values) Among Variables Assessed in the Study (n = 80)

	MMF-O	MMF-P	MOF	Weight	Height	BMI	Age
MMF-O	–						
MMF-P	0.587 (< .001)	–					
MOF	0.020 (.859)	0.111 (.327)	–				
Weight	−0.098 (.387)	0.070 (.540)	0.509 (< .001)	–			
Height	−0.064 (.570)	−0.011 (.920)	0.459 (<.001)	0.797 (< .001)	–		
BMI	−0.098 (.386)	0.101 (.373)	0.423 (< .001)	N/A	N/A	–	
Age	−0.127 (.260)	0.128 (.257)	0.009 (.940)	0.230 (.040)	0.113 (.317)	0.235 (.036)	–

N/A = not applicable because BMI is derived from weight and height.

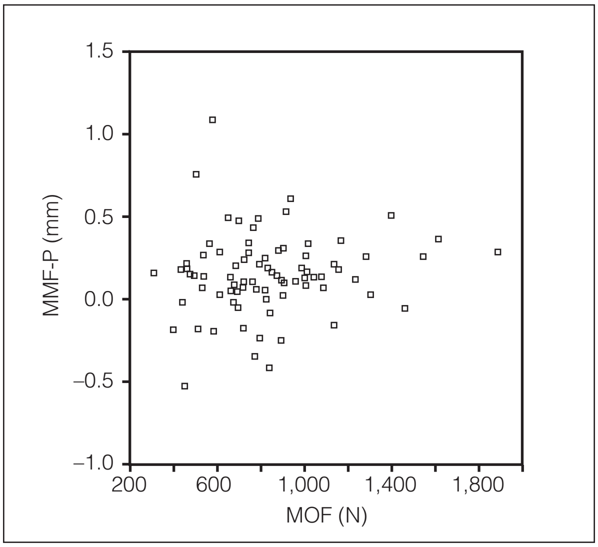

Fig 2a Scatterplot of MMF-P versus MOF.

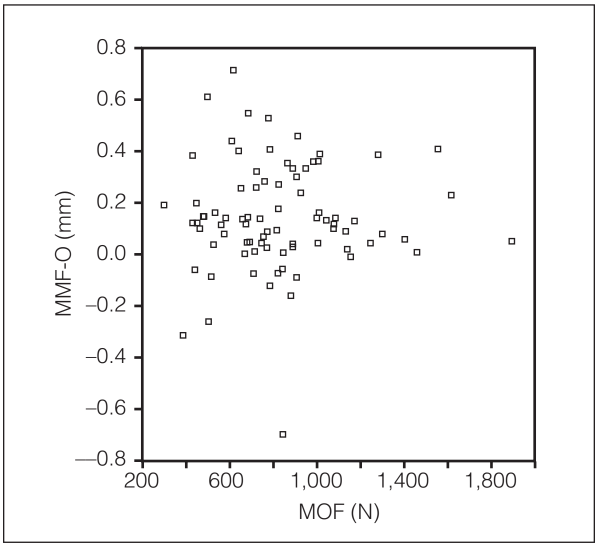

Fig 2b Scatterplot of MMF-O versus MOF.

The amplitude of MMF was large in this sample, ranging from –0.70 to 1.08 mm. A large intersubject variability of MMF is reported in the literature and ranges from some microns to more than 1 mm.[4] Multiple individual factors such as muscular force, facial geometry, and bone density may account for these discrepancies in MMF values.[2,10,20] Another reason for the large variability in MMF seems to be the different populations assessed, eg, young dentate subjects versus partial or totally edentulous subjects, and the different methods used to measure this deformation in vitro and in vivo, including transducers,[3,10,21] video recording,[11] dental impressions,[9,16] and 2- and 3-dimensional finite element analysis.[7,8,22] We also found large variability between men and women for both MMF and MOF values, but MMF did not vary as a function of gender in this sample.

During opening and protrusion movements, mandibular elastic distortion is complex and involves deformation in different spatial planes, such as medial convergence, corporal rotation, dorsoventral shear, and symphyseal bending.[3,23] For subjects that showed a negative MMF value, which means that intermolar distance increased in maximum opening and/or maximum protrusion from the rest position, a possible explanation is that other types of deformation may have been dominant over MMF.

In relation to MOF, the difference between men and women was statistically significant. Shinkai et al[24] also found lower MOF in women (407.4 N) than in men (644.5 N) using the same occlusal force equipment. The larger MOF for men may be partially explained by the fact that they had higher anthropometric measures than women. MOF had a significant positive association with all anthropometric variables, corroborating the results of Bakke et al.[13] Such variables may indirectly indicate the amount of muscular mass, and, consequently, muscular power. The larger the values of height, weight, and BMI were, the higher the values of MOF were. However, these anthropometric variables did not influence MMF. Since these anthropometric variables had significant correlation with MOF, this would be an additional indication that MOF did not have relation with MMF in this sample. Our MOF variability was similar to results reported by some previous studies,[14,25] but the values were higher than those reported by others.[13,14,18,26]

In summary, this study suggests that mandibular flexure is not associated with occlusal force, anthropometric variables, gender, or age in this sample of dentate adults. Perhaps the magnitude of MMF is larger in elderly subjects with absent posterior teeth, resorbed ridges, small symphysis height, and low bone density, as suggested previously. These subjects often are the patients who need total or partial posterior bilateral prostheses in the mandible. Further studies are warranted to investigate other factors that were not evaluated here, such as muscular insertion, mandibular geometry, facial pattern, bone density, and extreme groups of age, which may be related to the magnitude of MMF. Some of these variables or all of them combined with muscular force may explain the phenomenon of mandibular flexure in specific groups of patients.

Table 3 Comparison of the MMF Values as a Function of Potential Confounders (Student *t* Tests with Bonferroni Correction)

Confounders	n	MMF (mm) Mean	MMF (mm) SEM	*P*
Bruxism				
MMF-O				
Present	18	0.133	0.030	.718
Absent	62	0.148	0.030	
MMF-P				
Present	18	0.159	0.043	.852
Absent	62	0.147	0.033	
Muscular pain				
MMF-O				
Present	12	0.141	0.036	.947
Absent	68	0.145	0.027	
MMF-P				
Present	12	0.230	0.085	.223
Absent	68	0.136	0.029	
Tooth wear				
MMF-O				
Present	24	0.160	0.030	.923
Absent	54	0.155	0.029	
MMF-P				
Present	24	0.131	0.061	.520
Absent	54	0.169	0.029	
Mandibular first premolar				
MMF-O				
Present	8	0.140	0.031	.949
Absent	72	0.145	0.026	
MMF-P				
Present	8	0.031	0.060	.151
Absent	72	0.163	0.029	

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Literature Abstract

Microleakage of endodontically treated teeth restored with fiber posts and composite cores after cyclic loading: A confocal microscopic study

The aim of this study was to evaluate the leakage associated with 3 different adhesive systems used for fiber post and composite core restoration. Seventy-two mandibular premolars were divided into 6 groups. The first 3 were treated with endodontic sealer and temporary filling containing ZOE. Group 1 fiber posts were cemented using zinc phosphate cement; group 2 fiber posts were cemented with All Bond 2; group 3 with Panavia 21.The last 3 groups were treated with ZOE free material and cemented with All Bond 2, Panavia 21 dental adhesive, and Panavia Fluoro cements. All groups were subjected to cyclic loading using a frequency of 2 cycles/second, with a peak load of 125 N. The machine was stopped at 300,000 cycles. The specimens were immersed in Rhodamine B dye solution for 48 hours, then the teeth were sectioned parallel to the long axis and the halves were observed under a confocal microscope. On the basis of this study, it was concluded: coronal seal obtained with the 3-step dental adhesive (All Bond 2) produced less leakage than that obtained with other systems; light cured Panavia Fluoro cement showed less leakage than its predecessor (Panavia 21); and there was no significant difference in leakage scores among groups treated with and without zinc oxide-eugenol-based materials.

Mannocci F, Ferrari M, Watson T. *J Prosthet Dent* 2001;85:284–291. **Reference**: 36. **Reprints**: Dr Francesco Mannocci, Via Gemignani 3, 56015 Rigilone, Pisa, Italy. Fax: (390) 50-316-3235. E-mail: mannocci@sirius.pisa.it—*Khaldoun Alajlouni, UNMC College of Dentistry, Lincoln, NE*