Relationship Between Duration of Unilateral Masticatory Cycles and the Type of Lateral Dental Guidance: A Preliminary Study

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Purpose: This study assessed the duration of different phases of the chewing cycle and the height of the masticatory cycle in relation to the type of lateral guidance. ***Materials and Methods:*** Fifty-three subjects with the same type of lateral guidance on both sides were categorized into 3 groups: anterior protected articulation, canine protection, and group function. Overbite was measured clinically. Border jaw movements were recorded using a Sirognathograph, and the lateral guidance angle in the frontal plane was measured. Jaw movements during unilateral chewing of peanuts were recorded on the frontal plane using the Sirognathograph connected to an electrocardiograph used for transcription. A single masticatory cycle was divided into opening, closing, and occlusal-level phases. Masticatory parameters were analyzed by one-way analysis of variance, correlations, the paired Student *t* test, and multiple linear regression. ***Results:*** Women showed significantly longer total cycle duration than men. Subjects with canine protection showed the highest lateral guidance angle and the highest chewing cycle duration. Subjects with anterior protected articulation exhibited significantly longer occlusal-level phases. Fifty-nine percent of the variation in duration of the occlusal-level phase can be explained by the type of lateral dental guidance, gender, and lateral guidance angle. Only overbite was a predictor of height of mastication. ***Conclusion:*** The type of lateral guidance, gender, and frontal guidance angle are correlated with the duration of the occlusal-level phase during unilateral chewing of peanuts. The height of mastication cannot be explained by the type of lateral guidance. *Int J Prosthodont 2005;18:339–346.*

Masticatory movements are mainly affected by food characteristics[1–5] and occlusion. The occlusal factors include Angle class,[6] inclination of the occlusal plane and steepness of occlusal guidance,[7] occlusal facets of the posterior teeth,[8] and distance between the maxillary and mandibular posterior teeth in the lateral mandibular position.[9] The duration of different phases of the chewing cycle can be affected by wear, in the case of complete dentures,[10] gender,[11] age,[12,13] bolus size,[2,5] and the introduction of changes in occlusal guidance.[14]

Dental guidance during lateral movement may be provided by anterior teeth, canines alone, or 1 or more of the posterior working- or nonworking-side teeth. Dental guidance is an occlusal factor that can be changed by oral rehabilitation. Several studies have investigated the role of the type of lateral dental guidance in masticatory muscle activity[15,16] and temporomandibular joint disorders.[17,18] However, only a few studies have focused on the relationship between lateral guidance and chewing pattern, for instance, in

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patients rehabilitated with fixed complete implant dentures in the maxilla.[19] Alteration of occlusal guidance can influence masticatory closing and occlusal times,[14] but little information is available concerning the relationship between the type of dental guidance during lateral movement and mandibular movements while chewing.[20] This study aimed to assess the duration of the different phases of the chewing cycle and the height of the mastication cycle in relation to the type of lateral guidance (anterior protected articulation, canine protection, and group function).

Materials and Methods

Subjects

A total of 53 dentate subjects, 29 men and 24 women (age between 19 and 38 years, with a mean age of 26.6 years), were recruited from students and staff in the Faculty of Dentistry of the University of Barcelona. There was no history of orthodontic therapy and no symptoms indicative of temporomandibular disorders. All subjects had complete dentitions with no full-coverage restorations or tooth replacements, and the same type of lateral guidance on both sides. Informed consent was obtained from each subject. Subjects were categorized into three groups according to lateral guidance, as defined in the *Glossary of Prosthodontic Terms*[21]: anterior protected articulation (n = 16; 7 women and 9 men; mean age 26.7 years); canine protection (n = 20; 12 women and 8 men; mean age 27.2 years); and group function (n = 17; 5 women and 12 men; mean age 25.8 years).

Recording of Intraoral Guidance and Overbite

Recordings of the intraoral lateral tooth contacts were performed with occlusal registration strips (Bausch Articulating Paper BK09 40 μm, Dr Jean Bausch KG) with the subjects seated in an upright position and Frankfort horizontal plane kept as close to horizontal as possible. Two lines were marked on the labial surface of each subject's maxillary central incisors, separated by 3 mm, to control the lateral position. The examiner asked the subjects to close into intercuspal position with the occlusal registration strip placed on the occlusal surface. Afterward, the examiner asked the subjects to perform right lateral movement of the mandible for 3 mm while they maintained constant contact between the maxillary and mandibular teeth. The teeth holding the articulating paper were considered to have occlusal contact. This procedure was repeated on the left side of the mandible. One examiner performed all recordings to avoid interexaminer variation, and each recording was performed twice within an interval of a few minutes. When a difference in the record was present, a third examination was performed.

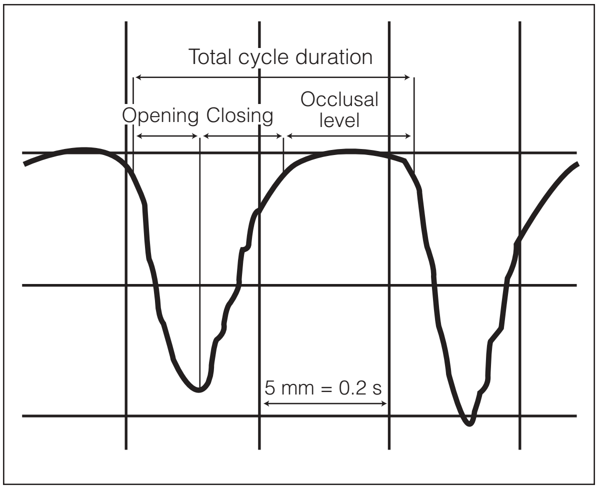
Recordings were classified as anterior protected articulation, canine protection, or group function. Anterior protected articulation was defined as the contact of 1 or more incisors without posterior contact. Canine protection was defined as the contact of only working-side maxillary and mandibular canines. Group function was defined as the contact of 1 or more posterior working-side teeth. Overbite was measured as the vertical distance between the incisal border of the mandibular right central incisor and that of the mandibular right central incisor when the teeth were in maximum intercuspation.

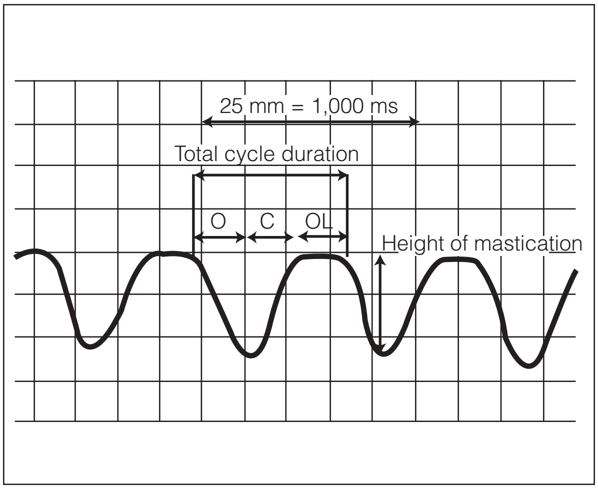
Recording of Jaw Movements

Border jaw movements were recorded using a Sirognathograph (Siemens). The Sirognathograph consists of a computing unit and a headset. After a magnet is attached to the mandibular incisors, 8 magnetometer sensors located in the headset detect mandibular movement, and the signals are then tracked in the sagittal, frontal, or horizontal planes on a plotter (Esterline). The Sirognathograph was recalibrated before each set of movements by its internal rezeroing mechanism. The position of the magnet in three-dimensional space was recorded to the nearest 0.1 mm along 3 orthogonal axes in real time. All recordings were made according to the method described by Lewin.[22]

Subjects were asked to sit upright in a wooden chair with no ferromagnetic material to prevent interference with the magnetic field. To achieve cranial stability, a padded headband connected to the chair was used. The magnet was attached to the labial surface of the mandibular central incisors with cyanoacrylate adhesive, offering no interference with occlusion or function. The headset of the Sirognathograph was then aligned with Frankfort horizontal plane in such a way that the magnet remained equidistant from both sensors. Subjects were asked to perform right- and left-sided lateral guidance movements, starting and ending in maximum intercuspation, and the jaw border movements were recorded in the frontal plane before chewing.

Jaw movements while chewing were recorded in the frontal plane using the Sirognathograph connected to an electrocardiograph used for transcription[23] (Cardiostat 31, Siemens). The electrocardiograph converted the closed chewing cycles into open chewing cycles recorded on a chart recorder at constant velocity (25 mm/s). Each participant was asked to chew 1 g of peanut on the right side of the dentition for 20 seconds; once the material was swallowed, the





Figs 1a and 1b Different phases of the masticatory cycle and the height of mastication in the electrocardiographic record. O = Opening phase; C = closing phase; OL = occlusal-level phase.

process was repeated on the left side. During chewing, compliance with use of the correct side was monitored by 1 of the investigators.

Data Analysis

For both left and right laterotrusive border movements, the lateral guidance angle in the frontal plane was measured as the angle between the horizontal plane and the line that connected intercuspal position, and a point located 2 mm from intercuspal position on the record. The lateral guidance angle in the frontal plane reflected the amount of descent of the mandible during lateral excursion.

For the masticatory parameters, the first cycle was disregarded, because it is usually an atypical cycle; the subsequent 10 cycles were then analyzed. The height of mastication was measured in each cycle stroke, from intercuspal position to maximum opening. Traces projected by the electrocardiograph were used to calculate the duration of each phase of the chewing cycles. For the analysis, a single masticatory cycle was divided into three separate phases: mandibular opening, mandibular closing, and occlusal-level phase. The occlusal-level phase corresponded to the horizontal part of the electrocardiographic record to a level 0.5 mm below this position. The opening and closing phase corresponded to the descending and ascending parts of the electrocardiographic record, respectively (Figs 1a and 1b). Since the constant velocity of the chart recorder was 25 mm/sec, 5 mm of the horizontal line was equivalent to 0.2 seconds.

Statistical Analysis

For each subject, the averaged data from 10 masticatory cycles was used for statistical analysis. A paired Student *t* test was calculated to determine differences between the two sides of mastication. Correlations between data from the left and right sides of mastication were analyzed. Correlations between different phases of mastication were also analyzed. In the correlation analyses, Pearson correlation coefficients were adopted.

Masticatory parameters were analyzed by one-way analysis of variance. Differences between groups were evaluated using the Duncan post hoc test. $P < .05$ was considered significant.

Five multiple linear regression models were studied using a stepwise variable selection method to determine the interaction of gender (female coded as 0, male as 1), age (in years), side of mastication (right coded as 0, left as 1), anterior protected articulation (no coded as 0, yes as 1), group function (no coded as 0, yes as 1), lateral guidace angle (in degrees), and overbite (in millimeters) with 5 different dependent variables. In the first, the dependent variable was total cycle duration; in the second, third, and fourth models, the dependent variables were opening, closing, and occlusal-level phase duration, respectively; and in the fifth model, the dependent variable was the height of the masticatory cycle. The assumption of normality of the dependent variables was tested by the Kolmogorov-Smirnov test. The statistical analyses were performed using SPSS version 11.0.1 (SPSS).

Table 1 Means (Standard Deviations) of Different Parameters, by Gender and by Side, Regardless of the Type of Lateral Guidance

Parameter	Total sample (n = 53)	Women (n = 24)	*P* (*t* test)	Men (n = 29)
Age (y)	26.6 (3.7)	25.8 (4.5)	NS	27.3 (2.6)
Overbite (mm)	3.13 (2.4)	3.29 (2.5)	NS	3.00 (2.3)
Right frontal angle (deg)	27.7 (13.0)	24.5 (13.3)	NS	30.4 (12.2)
Left frontal angle (deg)	29.4 (15.5)	28.7 (16.5)	NS	30.0 (14.9)
P (paired *t* test)	NS	NS		NS
Right total duration (ms)	576.9 (79.7)	601.3 (78.7)	.04	556.8 (76.1)
Left total duration (ms)	560.4 (86.7)	594.1 (93.1)	.01	532.5 (71.1)
P (paired *t* test)	.017	NS		.005
Right opening duration (ms)	180.9 (34.7)	185.1 (38.7)	NS	177.3 (31.2)
Left opening duration (ms)	176.1 (35.7)	183.1 (42.2)	NS	170.4 (28.7)
P (paired *t* test)	NS	NS		NS
Right closing duration (ms)	209.7 (43.4)	217.1 (51.5)	NS	203.5 (35.1)
Left closing duration (ms)	194.2 (40.7)	208.5 (50.3)	.02	182.5 (26.2)
P (paired *t* test)	.001	NS	NS	.001
Right occlusal duration (ms)	186.4 (45.0)	199.0 (45.1)	NS	175.9 (42.9)
Left occlusal duration (ms)	190.0 (48.5)	202.6 (50.7)	NS	179.1 (44.8)
P (paired *t* test)	NS	NS		NS
Right mastication height (mm)	11.5 (3.1)	10.92 (3.3)	NS	12.00 (3.0)
Left mastication height (mm)	12.2 (3.9)	10.79 (3.3)	.01	13.38 (4.0)
P (paired *t* test)	NS	NS		.03

NS = Not significant.

Table 2 Means ± Standard Deviations of Overbite, Frontal Angle, Time Measurements, and Height of Mastication by Type of Lateral Guidance

	Anterior protected articulation	Canine protection	Group function
Overbite (mm)	3.4 ± 2.7[b]	4.2 ± 1.8[b]	1.6 ± 1.7
Frontal angle (deg)	23.6 ± 12[a]	35.6 ± 14[b]	25.9 ± 14
Total duration (ms)	563 ± 71[a]	605 ± 88[b]	531 ± 72
Opening duration (ms)	166 ± 35[a]	190 ± 34	177 ± 33
Closing duration (ms)	167 ± 31[a,b]	226 ± 39[b]	206 ± 35
Occlusal-level duration (ms)	230 ± 38[a,b]	189 ± 33[b]	148 ± 30
Height mastication (mm)	10.5 ± 3.4[a,b]	12.3 ± 2.8	12.6 ± 4.1

[a]Significant difference with respect to canine protection
[b]Significant difference with respect to group function.

Results

No significant differences were found in age or gender distribution between the 3 different study groups. The data on different parameters relating to gender and side of chewing when all the study groups were analyzed together are shown in Table 1. No gender differences were observed for either overbite or frontal angle. Women showed a significantly longer total cycle duration than men on both chewing sides, mainly because of a longer closing phase, and a smaller height of mastication only during left-side chewing. The mean values for lateral guidance angle and the height of the masticatory cycle were similar for each side. The total duration of the masticatory cycle was slightly shorter when subjects chewed on their left side. This difference was due to a significant reduction in the duration of the closing phase in men, whereas the opening and occlusal-level phases were similar for men and women. The strongest correlation between sides was found in the duration of the occlusal-level phase ($r = 0.85$).

Subjects with group function had the smallest overbite compared with anterior protected articulation and canine protection (Table 2), whereas individuals with canine protection showed the largest lateral guidance angle in the frontal plane. Those with anterior protected articulation showed the lowest height of the masticatory cycle. When the entire chewing cycle duration was considered, canine protection subjects showed the highest value compared to subjects with anterior protected articulation or group function. Subjects with anterior protected articulation exhibited shorter opening and closing phases than subjects with canine protection. However, subjects with anterior protected articulation had a longer occlusal-level phase than those with canine protection or group function, and this phase was longer in individuals with canine protection than those with group function. A significant positive correlation ($r = 0.66$) was observed between opening phase duration and closing phase duration. However, occlusal phase duration was not correlated with either opening or closing phase duration. A weak ($r = -0.38$) but significant negative correlation was observed between the height of the masticatory cycle and duration of the occlusal-level phase of the chewing cycle (Fig 2).

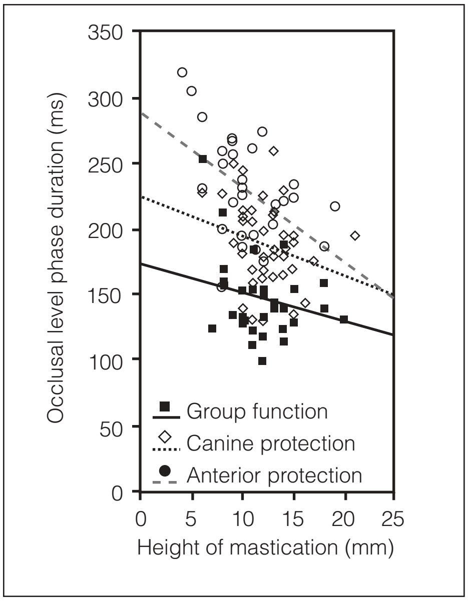


Fig 2 Correlation between height of masticatory cycles and duration of occlusal level phase for each group.

Table 3 Multiple Linear Regression Models

Model	Total duration (ms)	Opening phase (ms)	Closing phase (ms)	Occlusal phase (ms)	Height of mastication (mm)
Constant	681 (563 to 800)***	232 (177 to 286)***	264 (210 to 318)***	186 (136 to 236)***	8.5 (3.2 to 13.8)**
Age	0.7 (−3.4 to +4.9)	−0.7 (−2.6 to +1.2)	−0.04 (−1.9 to +1.8)	1.5 (−0.3 to +3.2)	0.1 (−0.1 to +0.3)
Gender	−35 (−66 to −3)*	−4.0 (−19 to +11)	−15 (−29 to −0.4)*	−16 (−29 to −2)*	1.2 (−0.3 to +2.6)
Side	−14 (−42 to +14)	−4.4 (−17 to +9)	−15 (−28 to −2)*	5.2 (−6.7 to +17)	0.6 (−0.7 to +1.9)
APA	−60 (−97 to −22)**	−29 (−46 to −2)***	−63 (−80 to −45)***	32 (16 to 48)***	−1.6 (−3.3 to +0.1)
GF	−91 (−133 to −48)***	−22 (−41 to −2)*	−27 (−46 to −7)**	−43 (−61 to −25)***	−0.3 (−2.2 to +1.6)
Angle	−1.4 (−2.5 to −0.3)**	−0.2 (−0.7 to +0.3)	−0.3 (−0.8 to +0.2)	−1.0 (−1.4 to −0.5)***	0.05 (−0.00 to +0.10)
Overbite	−9.6 (−19 to +0.2)	−2.6 (−5.8 to +0.5)	−3.0 (−6.1 to +0.1)	0.3 (−2.6 to +3.2)	−0.3 (−0.6 to −0.01)*
R^2	0.28	0.14	0.43	0.59	0.19
P	.000	.041	.000	.000	.003

B, regression coefficients (95% CI of B). $*P < .05$; $**P < .01$; $***P < .001$.
APA = Anterior protected articulation; GF = group function.

The results of the multiple linear regression analyses are presented in Table 3. Stepwise multiple linear regression showed gender, anterior protected articulation, group function, and lateral guidance angle to be independent predictors of total cycle duration. Age, side of mastication, and overbite were not found to be predictors of total cycle duration (R^2 for the overall model 0.28, $P < .0005$). Although the presence of anterior protected articulation instead of canine protection was a predictor of increased occlusal-level phase duration (32 ms; 95% confidence interval [CI], 16 to 48 ms), it was also a predictor of decreased total cycle duration (60 ms; 95% CI, 22 to 97 ms). This was a result of the fact that the presence of anterior protected articulation was a predictor of both decreased opening (29 ms; 95% CI, 12 to 46 ms) and closing (63 ms; 95% CI, 45 to 80 ms) phases. Whereas only the presence of anterior protected articulation or group function were predictors of a shorter opening phase ($R^2 = 0.14$, $P = .04$), male gender, left-side function, and presence of anterior protected articulation or group function were predictors of a shorter closing phase ($R^2 = 0.43$, $P < .0005$). The fourth regression model showed that 59% of the variation in duration of the occlusal-level phase could be explained by the type of lateral dental guidance, gender, and the lateral guidance angle. An increase of 10 degrees in the lateral guidance angle implies a 10-ms reduction in the duration of the occlusal-level phase. Only overbite was a predictor of the height of the masticatory cycle.

Discussion

The present study examined whether the type of lateral guidance affects the duration of the different phases of the masticatory cycle and the height of mastication during unilateral chewing of peanuts. The results showed that whereas subjects with canine protection had longer opening and closing phases as well as longer total cycle length, group function exhibited the shortest occlusal-level phase. Subjects with anterior protected articulation spent the least time in the opening and closing phases, but they spent the most time in the occlusal-level phase. These results were observed after adjustment for age, gender, side of mastication, lateral guidance angle, and overbite.

Subjects with group function showed a shorter total cycle duration than those with canine protection. Because these two types of occlusal guidance showed similar masticatory cycle heights, this suggests that the velocity was greater in individuals with group function. In a previous report, no cycle duration differences were apparent between individuals rehabilitated with group function or with canine protection, but mandibular velocity was significantly greater when the subjects were rehabilitated with group function.[19] In the present study, subjects with anterior protected articulation spent more time in the occlusal-level phase, probably as a result of the necessity of applying a sustained biting force to compensate for the absence of posterior contacts during laterotrusion. Moreover, it was reported previously that subjects displaying a chopping chewing pattern had posterior teeth that were more tightly intercuspated in centric occlusion, and exhibited greater separation between the maxillary and mandibular posterior teeth on the working side than those displaying a grinding chewing pattern.[9]

In the present study, the type of lateral guidance was examined in edge-to-edge position (3 mm lateral to intercuspal position at the incisors). It is known that tooth contact in lateral movement is a dynamic process. Therefore, examining tooth contact in a single position may not adequately reflect the pattern of lateral glide movement, and a canine-protected pattern of occlusion increases as teeth approach the edge-to-edge position.[24] Average occlusal glide lengths in a sample of women with natural dentition were 1.29 mm and 1.55 mm on the closing and opening pathways, respectively, while chewing gum.[25] However, the chewing cycle appears to increase the lateral component of its movement when increased chewing efficiency is required, eg, with increased hardness of the bolus.[26]

The length of the occlusal glide during mastication has been reported to be between 1 and 4 mm at the incisors.[27] Ogawa et al[28] recommended examination of the pattern of occlusal contact in the 3-mm position as an edge-to-edge position in the parafunctional range, and in the 0.5-mm position as a position close to maximum intercuspation in the functional range.[28] In the present study, the type of lateral guidance was examined in the edge-to-edge position, because chewing hard food and parafunctional activity are the main concerns when oral rehabilitation is required.

One of the limitations of this study was that only one test food was used. Therefore, the results cannot be extrapolated to other food because masticatory patterns depend on the food fragmentation index,[1] bolus hardness,[3] food consistency,[4] and food size.[2] Peanuts were chosen because they are nonsynthetic, relatively hard, popular, swallowable, and represent a test food used in previous studies of mastication.

Regardless of the type of lateral guidance, the total cycle duration and the relative length of its phases observed in the present study agree with the results of previous reports that used peanuts or almonds as test foods.[12,13,29] However, slower cycles and/or less relative time spent in the occlusal-level phase were observed in studies that used chewing gum or gummy jellies.[2,3,11,14] These differences may be explained by the faster rate of chewing cycles and the greater amount of time spent in the occlusal phase, resulting in more efficient chewing.[30] Moreover, people usually chew gum for entertainment, whereas the aim of chewing peanuts or almonds is to break down the food, which probably requires greater velocity to be efficient. The Sirognathograph is a device that has been found to be reliable for the evaluation of the movement of an incisor point on the mandible during chewing.[31] The connection between the Sirognatograph and an electrocardiograph has been described previously.[23] The electrocardiograph converts the closed chewing cycles into open chewing cycles using a chart recorder set at a constant velocity, allowing us to measure the timing of each cycle and the height of mastication.

Although men spent less time both in the closing phase and in the total chewing cycle and had a greater height of masticatory cycle during left-side chewing, multiple regression showed that chewing side only affects the closing phase after adjustment by other variables. The side difference may be attributable to the hemispheric laterality that determines laterality in the function of peripheral organs—thus, most patients prefer chewing on the right side.[32] Unfortunately, chewing side preference was not recorded in the present study. Women showed a significantly longer total cycle duration than men because of the length of the closing and occlusal-level phases. However, women exhibited a lower height of mastication on the left side. This suggests that chewing velocity is higher in men than in women. These results are very similar to those of other studies.[11,12,33,34] The fact that women remain longer in the occlusal-level phase may be related to lower muscular force, dentoskeletal morphology, genetics, and sociocultural pressures.[30,35]

The height of the masticatory cycle observed in this study was very similar to that found in other studies,[12,13,29,34] most of which used peanuts as a test food. In the present study, no difference in the height of the masticatory cycle was found between canine protection and group function in the natural dentition. However, total opening and maximal lateral movement have been shown to be greater when rehabilitation is performed with group function than with canine guidance.[19] This discrepancy could be explained by differences in subjects' ages, as well as the difference between mastication with natural and prosthetic teeth. Although the height of the masticatory cycle was significantly lower in subjects with anterior protected articulation, regression analysis did not show this relationship as significant ($P = .06$), after adjustment for overbite and other variables. Since only 19% of the variation in the height of mastication can be explained by age, gender, side of mastication, type of lateral guidance, lateral guidance angle , and overbite, other inter and intra individual factors must be involved. A significant negative correlation has been found between the duration of the occlusal-level phase and the height of mastication in each type of lateral guidance. It is possible that subjects who spend more time in the occlusal-level phase do not need to open their jaws as wide to break down hard food.

Subjects with canine protection spent longer in the opening and closing phases as well as in the total cycle, whereas group function subjects showed the shortest occlusal-level phase. Subjects with anterior protected articulation spent the least time in the opening and closing phases, but they exhibited the longest occlusal level-phase. The variation in the duration of the occlusal-level phase can be explained by the type of lateral dental guidance, gender, and lateral guidance angle. Only overbite was a predictor of the height of the masticatory cycle.

Masticatory movements are governed mainly by the central nervous system and are influenced by peripheral receptors.[36] In spite of the limitations of this study, the results suggest that the different types of lateral dental guidance are well defined structurally and functionally. Therefore, when certain prosthodontic treatments are performed to introduce changes in dental guidance—eg, changes in anterior guidance, restorations supported by implants, splinting of teeth—the chewing pattern is likely to change, which could hinder adaptation. It is possible that the more closely the new occlusion resembles the occlusion before oral rehabilitation, the easier it will be for the patient to accommodate theses changes.[37] Further studies are needed to clarify the influence of changes in occlusion on the chewing pattern.

References

1. Agrawal KR, Lucas PW, Bruce IC. The effects of food fragmentation index on mandibular closing angle in human mastication. Arch Oral Biol 2000;45:577–584.
2. Miyawaki S, Ohkochi N, Kawakami T, Sugimura M. Effect of food size on the movement of the mandibular first molars and condyles during deliberate unilateral mastication in humans. J Dent Res 2000;79:1525–1531.
3. Anderson K, Throckmorton GS, Buschang PH, Hayasaki H. The effects of bolus hardness on masticatory kinematics. J Oral Rehabil 2002;29:689–696.
4. Filipic S, Keros J. Dynamic influence of food consistency on the masticatory motion. J Oral Rehabil 2002;29:492–496.
5. Bhatka R, Throckmorton GS, Wintergerst AM, Hutchins B, Buschang PH. Bolus size and unilateral chewing cycle kinematics. Arch Oral Biol 2004;49:559–566.
6. Pröschel P, Hofmann M. Frontal chewing patterns of the incisor point and their dependence on resistance of food and type of occlusion. J Prosthet Dent 1988;59:617–624.
7. Ogawa T, Koyano K, Umemoto G. Inclination of the occlusal plane and occlusal guidance as contributing factors in mastication. J Dent 1998;26:641–647.
8. Kim SK, Kim KN, Chang IT, Heo SJ. A study of the effects of chewing patterns on occlusal wear. J Oral Rehabil 2001;28:1048–1055.
9. Nishio K, Miyauchi S, Maruyama T. Clinical study on the analysis of chewing movements in relation to occlusion. Cranio 1988;6:113–123.
10. Karlsson S, Persson M, Carlsson GE. Mandibular movement and velocity in relation to state of dentition and age. J Oral Rehabil 1991;18:1–8.
11. Buschang PH, Hayasaki H, Throckmorton GS. Quantification of human chewing-cycle kinematics. Arch Oral Biol 2000;45:461–474.
12. Kiliaridis S, Karlsson S, Kjellberg H. Characteristics of masticatory mandibular movements and velocity in growing individuals and young adults. J Dent Res 1991;70:1367–1370.
13. Papargyriou G, Kjellberg H, Kiliaridis S. Changes in masticatory mandibular movements in growing individuals: A six-year follow-up. Acta Odontol Scand 2000;58:129–134.
14. Ogawa T, Ogawa M, Koyano K. Different responses of masticatory movements after alteration of occlusal guidance related to individual movement pattern. J Oral Rehabil 2001;28:830–841.
15. Belser UC, Hannam AG. The influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. J Prosthet Dent 1985;53:406–413.
16. Akoren AC, Karaagaçlioglu L. Comparison of the electromyographic activity of individuals with canine guidance and group function occlusion. J Oral Rehabil 1995;22:73–77.
17. Kahn J, Tallents RH, Katzberg RW, Ross ME, Murphy WC. Prevalence of dental occlusal variables and intraarticular temporomandibular disorders: Molar relationship, lateral guidance, and nonworking side contacts. J Prosthet Dent 1999;82:410–415.
18. al-Ani MZ, Gray RJ, Davies SJ, Sloan P. A study of the relationship between lateral guidance and temporomandibular joint internal derangement. Eur J Prosthodont Restorative Dent 2003;11:65–70.
19. Jemt T, Lundquist S, Hedegard B. Group function or canine protection. J Prosthet Dent 1982;48:719–724.
20. Ahlgren J. Masticatory movements in man. In: Anderson DJ, Matthews B (eds). Mastication. Bristol: John Wright, 1976:119–130.
21. The glossary of prosthodontic terms, seventh edition. J Prosthet Dent 1999;81:39–110.
22. Lewin A. Electrognathographics. Atlas of Diagnostic Procedures and Interpretation. Chicago: Quintessence, 1985.

23. Salsench J, Torrent J, Pascual M, de Caso J. A new method of recording diverse mandibular movements. Acta Odontostomatol (Paris) 1986;40:29–38.
24. Ingervall B, Hähner R, Kessi S. Pattern of tooth contacts in eccentric mandibular positions in young adults. J Prosthet Dent 1991;66:169–176.
25. Hayasaki H, Sawami T, Saitoh I, Nakata S, Yamasaki Y, Nakata M. Length of the occlusal glide at the lower incisal point during chewing. J Oral Rehabil 2002;29:1120–1125.
26. Yamashita S, Hatch JP, Rugh JD. Does chewing performance depend upon a specific masticatory pattern? J Oral Rehabil 1999;26:547–553.
27. Suit SR, Gibbs CH, Benz ST. Study of gliding tooth contacts during mastication. J Periodontol 1976;47:331–334.
28. Ogawa T, Ogimoto T, Koyano K. Validity of the examination method of occlusal contact pattern relating to mandibular position. J Dent 2000;28:23–29.
29. Chew CL, Lucas PW, Tay DKL, Keng SB, Ow RK. The effect of food texture on the replication of jaw movements in mastication. J Dent 1988;16:210–214.
30. Wilding RJ, Lewin A. The determination of optimal human jaw movements based on their association with chewing performance. Arch Oral Biol 1994;39:333–343.
31. Kazazoglu E, Heath MR, Ferman AM, Davis GR. Recording mandibular movement: Technical and clinical limitations of the Sirognathograph. J Orofac Pain 1994;8:165–177.
32. Nissan J, Gross MD, Shifman A, Tzadok L, Assif D. Chewing side preference as a type of hemispheric laterality. J Oral Rehabil 2004;31:412–416.
33. Neill DJ, Howell PG. A study of mastication in dentate individuals. Int J Prosthodont 1988;1:93–98.
34. Youssef RE, Throckmorton GS, Ellis E III, Sinn DP. Comparison of habitual masticatory patterns in men and women using a custom computer program. J Prosthet Dent 1997;78:179–186.
35. Gerstner GE, Parekh VV. Evidence of sex-specific differences in masticatory jaw movement patterns. J Dent Res 1997;76:796–806.
36. Turker KS. Reflex control of human jaw muscles. Crit Rev Oral Biol Med 2002;13:85–104.
37. Klineberg I, Murray G. Osseoperception: Sensory function and proprioception. Adv Dent Res 1999;13:120–129.