Occlusal forces during chewing—Influences of biting strength and food consistency

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In a previous article[1] the magnitude and time relationships of occlusal forces in chewing and swallowing for 20 good occlusion subjects were described. Since maximum biting strength varied considerably within the 20 subjects,[2] this article compares chewing force characteristics in subjects with low and high biting strength values. Force changes throughout the chewing series from the time the food entered the mouth until it was swallowed were also investigated in this study. Foods of different consistencies were compared separately to give additional insight into the masticatory system's adaptation to variations in the consistency of the bolus.

METHODS

Occlusal forces during chewing were measured with a sound transmission system. The advantage of this system was that total biting force across all the teeth was measured without intraoral instrumentation. Sinusoidal sound vibration was introduced at the forehead and conducted to the chin through tooth, muscle, and temporomandibular joint (TMJ) pathways. The greater the force between the mandible and maxillae, the greater the amplitude of vibration received by the chin accelerometer (Fig. 1). The timing between the force and the chewing movements was measured to within 15 msec accuracy. This system has a great advantage over the integrated electromyographic (EMG) methods for measuring chewing forces due to the substantial and varying time delay occurring between the integrated EMG activity and occlusal force period.[1, 3, 4] The maximum error in measuring amplitude of force was 25% of full scale. Vertical jaw movement was measured with a strain gauge transducer mounted on a head frame and tied to the chin (Fig. 1).[1, 2, 5]

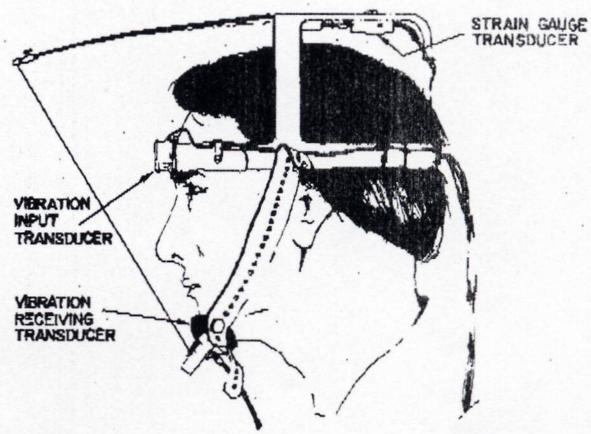

Fig. 1. Vibration bite force system. Chewing force was measured using amplitude of sound vibration transmitted from forehead to chin. Vertical jaw movements were measured with strain gauge transducer mounted on head frame and tied to chin. No intraoral instrumentation was used.

Twenty subjects with good occlusion were selected for this study. The 13 men and 7 women ranged from 17 to 55 years of age. Criteria for good occlusion included: (1) 28 to 32 teeth in good arch alignment present, (2) no abnormal tooth abrasion or mobility, (3) no teeth in crossbite, (4) posterior teeth intercuspated according to Angle's Class I occlusion, (5) normal gingival tissues, (6) lack of muscle pain and other dysfunction symptoms, (7) no balancing interferences, and (8) anterior guidance in right and left lateral and protrusive movements.

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Table I. Occlusal forces during chewing*

Biting strength (pounds, Kg)	N	Force closing (pounds, Kg)	Force at occlusion (pounds, Kg)	Force opening (pounds, Kg)
55-120, 25-54.5 low	5	13.2, 6	43, 19.5	10.3, 4.7
121-209, 55-95 intermediate	10	21.2, 9.6	49.9, 22.7	13.7, 6.3
210-280, 95.5-127.3 high	5	18, 8.2	92.1, 41.9	12.2, 5.5
128.8, 58.5 kg overall averages	20	18.2, 8.3	58.7, 26.7	12.5, 5.7

*An average of 266 chews per subject over six foods were used. All 20 subjects had good occlusion.

Table II. Duration of chew*

Biting strength	N	Time of chew (msec)	Time of occlusal phase (msec)	Time of high force during occlusal phase (msec)
55-120, 25-54.5 low	5	661.64	204.51	142.14
121-209, 55-95 intermediate	10	717.32	187.24	108.01
210-280, 95.5-127.3 high	5	590.08	198.13	102.63
128.8, 58.5 overall averages	20	671.59	194.28	115.2

*An average of 266 chews per subject over six foods were used. All 20 subjects had good occlusion.

Table III. Comparing chewing forces for hard and soft foods*

Food	Force closing (pounds, Kg)	Force at occlusion (pounds, Kg)	Force opening (pounds, Kg)
Peanuts	26.98, 12.26	78.35, 35.57	14.60, 6.64
Cheese	15.71, 7.14	50.35, 22.89	11.15, 5.07

*Twenty subjects with good occlusion.

Data were collected for right and left sides during unilateral chewing of cheese, raisins, bread, beef, carrots, and gum. An average of 266 chews was analyzed for each subject. The food was cut into bite size portions. The only instruction given the subject was designation of the side on which to chew.

The data were partitioned into three groups depending on the maximum biting strength of the subjects: (1) low biting strength, 55 to 120 pounds, (2) intermediate biting strength, 121 to 209 pounds, and (3) high biting strength, 210 to 280 pounds (Tables I and II). Occlusal force and duration characteristics of chewing were tested statistically between the low and high biting force groups only. The values for the intermediate biting strength group were listed in Tables I and II for reference.

The three phases of tooth contact that occur during chewing have been described by Ahlgren.[6] The closing phase refers to the initial contact before the cusps reach their intercuspal position (IP). The occlusal phase is the cusp contact in the IP where movement usually pauses for 20% of the total time of the chewing cycle and the highest force is produced. The opening phase refers to tooth contact that is still maintained as the cusps leave IP before their actual separation. The closing, occlusal IP, and opening phases during chewing are demonstrated by computer drawn plots, which were recorded by the Replicator System (Fig. 2).[7, 8]

FINDINGS

An analysis of variance showed that forces were greatest in the occlusal phase, second greatest in closing, and least during the opening phase ($\alpha = .01$) (Table I). No differences were found between right and left side chewing ($\alpha = .05$). A comparison of the maximum biting strength of the subjects with the lowest maximum occlusal force (55

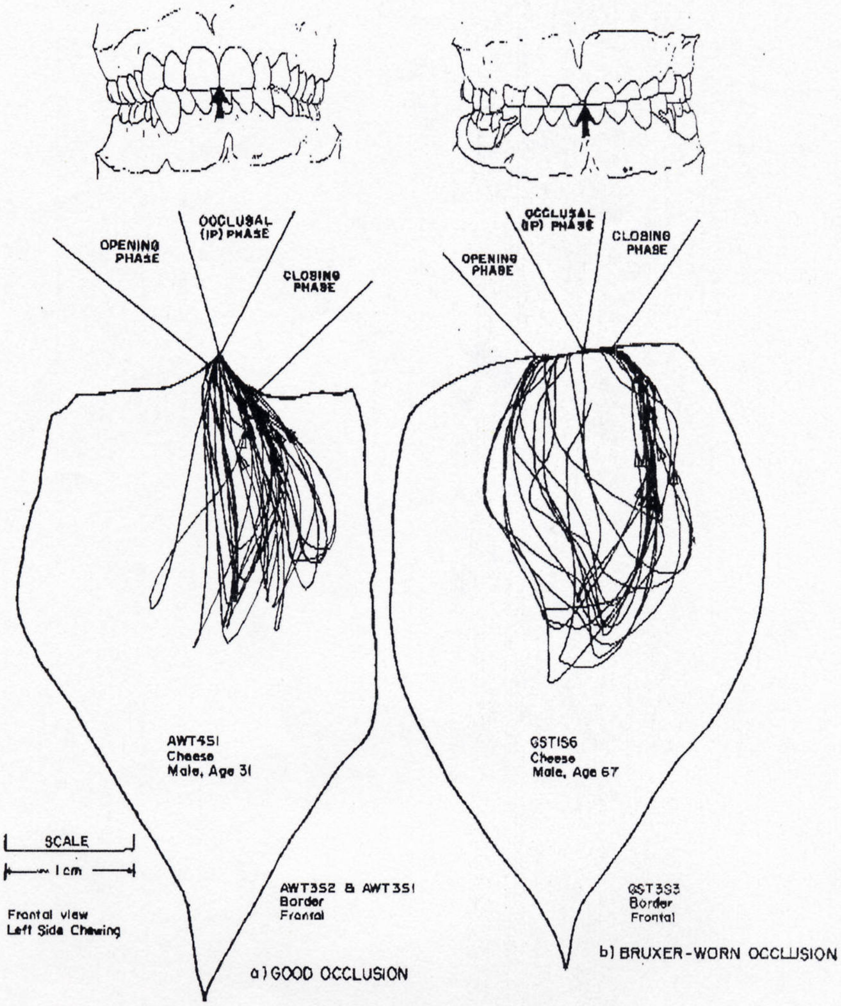

Fig. 2. Closing, occlusal IP, and opening phases during chewing are demonstrated by computer drawn plots, which were recorded by Replicator System. Subjects are shown for illustration purposes only. Their data were not included in study because criteria did not include crossbite or worn occlusions.

to 120 pounds) to the subjects with the greatest occlusal force (210 to 280 pounds) showed that the strong group used more force in the occlusal phase (92.1 versus 43.0 pounds), but forces in the closing and opening phases were not significantly different ($\alpha = .05$). The time of the chew, the time of the high force in the occlusal phase, and the time in the occlusal phase when the teeth were in IP were all longer for the weak group than the strong group ($\alpha = .05$) (Table II).

The chewing series from the first chew to swallowing averaged 15.5 chews (standard deviation 2.8 chews) for the 20 subjects chewing the six foods. No relationship was found between the average number of chews in the masticatory series and biting strength of the subject for either soft (cheese) or hard (peanut) foods.

The average maximum force at occlusion increased throughout the chewing series for both soft and hard foods (Fig. 3). The bivariate, linear regression for peanut chewing ($r = .85$) and for cheese ($r = .77$) were statistically significant ($\alpha = .05$).

The average maximum biting force during the closing phase showed a decrease throughout the chewing series for hard food chewing ($r = -.68$), which was statistically significant ($\alpha = .05$) (Fig. 4). The increase shown for soft food ($r = .52$) in Fig. 3 was not significant. Chewing forces during closing and during the occlusal phases were greater for hard food than for soft food ($\alpha = .05$) (Table III, Figs. 3

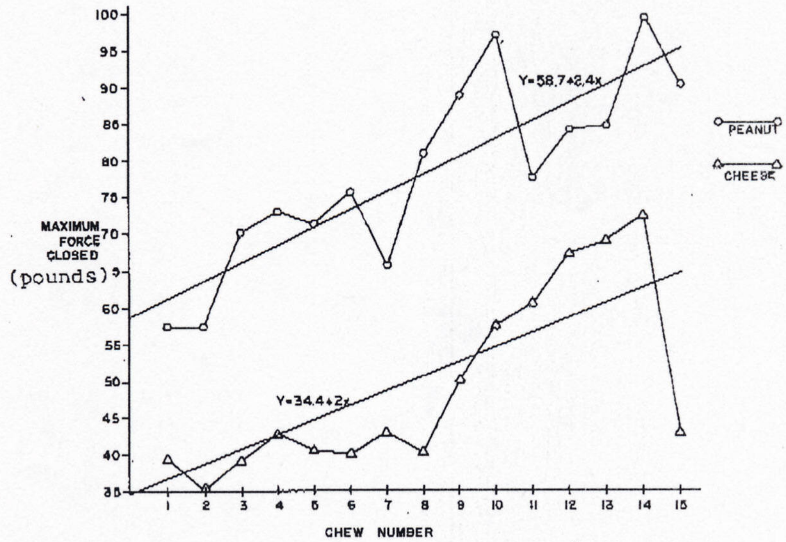

Fig. 3. Maximum force during pause at IP increased throughout chewing series for hard food ($r = .85$) and soft food ($r = .77$). These relationships were statistically significant ($\alpha = .05$). It is surprising that such high forces occurred when jaw was "motionless" at IP and that force increased as bolus reduced and softened.

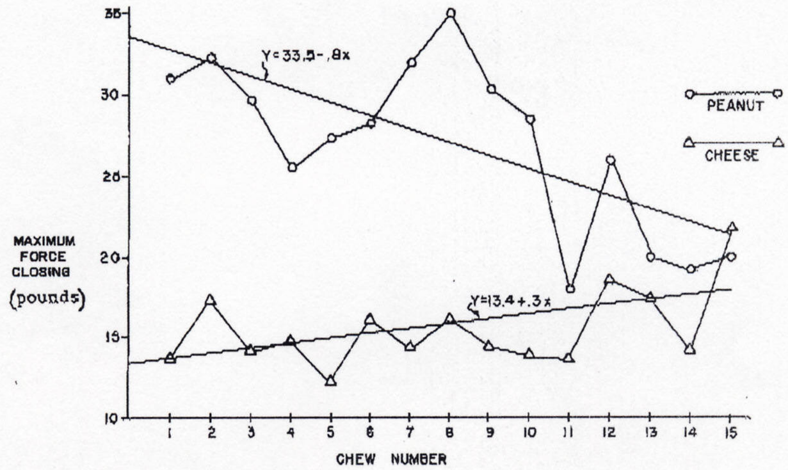

Fig. 4. Maximum force during closing phase showed a decrease for hard food chewing ($r = -.68$), which was statistically significant ($\alpha = .05$). Increase shown for soft food ($r = .52$) was not significant. As hard food softened near swallowing, closing force approached that of soft food.

and 4). As the hard food became softer near swallowing, the closing force approached the closing force of the soft food (Fig. 4).

During chewing, the time with the jaw motionless at the IP position increased throughout the chewing series (Fig. 5). The bivariate linear regression ($r = .86$) was significant statistically ($\alpha = .05$). The overall average duration of the pause at IP was 194, with a standard deviation 38 msec. No significant increase in the total time of the chew was found during the masticatory series ($r = .34$) (Fig. 6).

DISCUSSION

Chewing forces during closing and at occlusion were affected by the consistency of the food. Forces were greater for hard food than for soft food. Closing force decreased thoughout the chewing series for hard food and, near swallowing, closing forces for

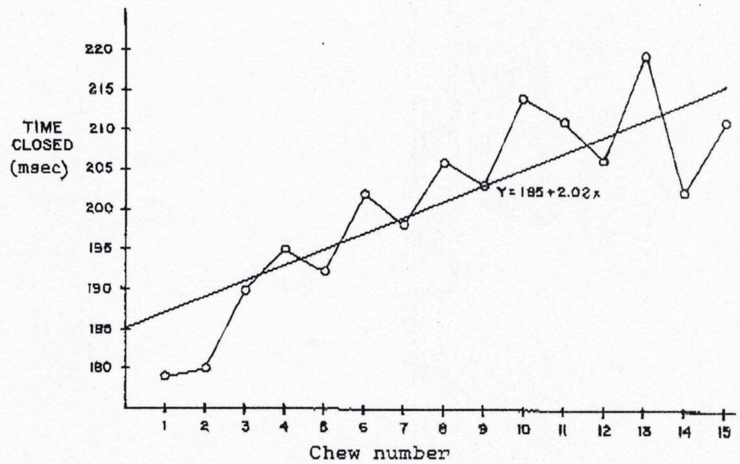

Fig. 5. Time with jaw motionless at IP increased throughout chewing series (r = .86). This increase was statistically significant (α = .05).

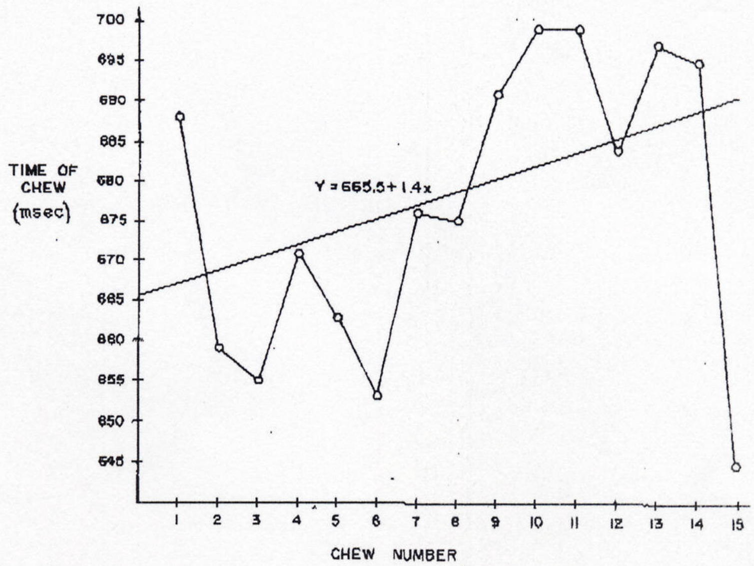

Fig. 6. No significant increase was found in the total time of chew during chewing series (α = .05).

hard and soft foods were nearly equal. These findings seem logical since harder foods should require more force to mechanically break down, especially in the closing phase. It is somewhat surprising, however, that the greatest forces in chewing should occur at occlusion when the jaw is "motionless." Furthermore, as shown in Fig. 3, this force at occlusion and its duration of application (Fig. 5), increase throughout the chewing series from the first chew, when the food has just entered, until swallowing. These findings indicate that the high force applied at occlusion is related to breakdown of the food, since force is dependent upon the original consistency of the food. Although the jaw appears motionless, very minor movement may occur and be effective for food breakdown at these high force levels. The increase in force at occlusion as the chewing series progresses seems in contradiction to the findings that higher forces are used for more resistant foods, since the food softens as the chewing series progresses. This increase in force during the chewing series appears inherent in the neuromuscular system and only the beginning force level is related to the consistency of the food.

in tooth to tooth contact

The comparison of chewing force for subjects with low biting strength to those with high biting strength was surprising in view of the moderate differences shown in the closing and opening phases, which were not statistically significant at $\alpha = .05$. These forces appear to be limited by the resistance of the food (Table III). It was not until the IP was reached that the high biting strength subjects used much greater occlusal force in chewing than did the weak biting strength subjects (92.1 versus 43.0 pounds). The weak biting strength subjects used about one-half of their total biting force in the occlusal phase compared to one-third for the high biting strength subjects. The force at IP is therefore related to both the subject's biting strength and the resistance of the food.

In regard to the adequacy of complete dentures for chewing, Haraldson et al.[9] reported that chewing forces measured in complete denture wearers are only one-fifth to one-sixth that produced by subjects with their natural dentition. One-fifth of the average maximum force in each chew is 11.7 lbs, which is just slightly below the closing force levels for the weak group (13.2 pounds) but far below their force levels at occlusion (43 pounds). It appears then that on the average, complete denture wearers have barely adequate force values required for breaking down food in the closing phase, and these values are far from adequate when applying the high force at IP. The function of the high force application at IP has not been completely clarified.

The great difference in forces used by the complete denture wearer compared with the natural dentition subject may explain differences reported in previous studies in comparison to this study. Bearn[10] reported a *decrease* in peak force during the chewing series, while in this study an *increase* was observed in the occlusal phase. However, Bearn's study is consistent with our data in that higher forces were used for the chewing of more resistant foods. Furthermore, our data are also consistent with findings for complete denture wearers as reported by Atkinson and Shepherd[11] in that chewing forces are highest at occlusion. Additional findings in complete denture wearers have been summarized in a review by Bates et al.[12]

In a study of 24 subjects with natural dentition, Conant[13] used a method similar to the one used in this study and reported a reduction in biting force during the chewing series, especially in the first chews. These data are consistent with our closing phase measurements but not with our measurements in the occlusal phase. Conant indicated that the maximum force normally occurred in lateral working and balancing excursions, rather than in IP, which is in disagreement with this study.

One possible explanation for these differences is that Conant's indicator of jaw movement may not have accurately separated the closing, closed, and opening phases. Conant used a telegraph key operated manually while observing jaw movement with the lip retracted. It is difficult to accurately mark the jaw movement in this manner. Another explanation might be that occlusal sounds during lateral excursions may not have been sufficiently filtered electrically and thus may have been misinterpreted as increased occlusal force. Also, at Conant's frequency of 1,000 Hz, occlusal sounds could have been produced adding to the sound energy passing the filter. It is possible that unwanted sounds also passed the filter in this study; however, a double hetrodyning 100 Hz filter was used to minimize this risk. Also, a large sample was used in this study, to minimize the importance of a few readings which could have been increased by unwanted sound energy.

Using telemetry from a two-pontic partial denture in three subjects, DeBoever et al.[14] reported that chewing forces were greater for chewing hard food than soft food, which is in agreement with this study. These investigators did not find a pattern in which the peak force occurred in the chewing series. In this study, occlusal force at IP increased through the chewing series, and closing force for hard food decreased.

Graf[15] and DeBoever et al.,[14] in two and three subjects, respectively, found that chewing forces were greater on the working side (bolus) than on the nonworking side. In contrast, in an early study involving four subjects, Anderson and Picton[16] did not find this difference. When the instrumented "tooth" was raised above the general occlusal level, the resulting loads were not increased as much as had been expected, indicating that force regulation did occur.[15, 16]

In a recent study of 10 natural dentition subjects chewing bread, Jemt et al.[17] reported that the duration of the occlusal phase was constant over the chewing series. This is in contrast to this study in which an increase in duration of the occlusal period over the chewing series was observed. This study's finding of an overall average of 15.5 chews for six foods was a little lower than the 19 chews for bread reported by Jemt et al.[17]

CONCLUSIONS

Jaw forces were surprisingly high during chewing. Forces were greatest during the 194 msec pause in jaw movement when the teeth were in the intercuspal position (58.7 pounds, 26.7 kg), considerably less during closing (18.2 pounds, 8.3 kg), and least during opening (12.5 pounds, 5.7 kg). The importance of occlusal stability in the intercuspal position would appear to be of utmost clinical significance.

Chewing forces were affected by the consistency of the food. Forces during closing and at IP were greater for hard food than soft food.

Closing force for hard food decreased during the chewing series, while closing force for soft food did not change significantly. In contrast to force during closing, the force during the pause in movement at IP increased during the chewing series. This was true for both hard and soft foods. The duration of the pause at the intercuspal position increased along with the increase in force.

The lengthy pause at IP does appear to be related to the breakdown of the food, since force is greater for harder foods. However, it is mysterious that the magnitude and duration of the force in IP should increase throughout the chewing series as the bolus softens and reduces. This increase appears inherent in the neuromuscular system and is only related to the hardness of the food in as far as establishing the initial force level from which the increase begins. This indicates a high level of tooth-to-tooth force and emphasizes the importance of occlusal relationships in IP.

Resistance increase as teeth touch

Near contact centric interferance can increase force

During chewing, the subjects with high biting strength values used more force in the occlusal phase at IP than the subjects with low biting strength values. The differences in forces during closing and opening phases for these two groups were not statistically different. The high biting strength group demonstrated a somewhat shorter time duration for the chewing stroke, the period of the closing phase, and the period of high force at IP than the low biting strength group.

Comparing the data for natural dentition subjects to the data from studies of complete denture wearers indicates that the forces used by complete denture subjects is only barely adequate for breaking down food in the closing phase and far from adequate for applying a high force at IP. The importance of the high force at IP has not been clearly established.

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