From:
The Departments of Clinical Physiology and Prosthetics, University of Umeå, Sweden

ISOMETRIC BITE FORCE AND ITS RELATION TO GENERAL MUSCLE FORGE AND BODY BUILD

by
HÅKAN LINDERHOLM
ARNE WENNSTRÖM

INTRODUCTION

There are many reports from investigations on bite or masticatory force (*Black*, 1895; *Morelli*, 1928; *Anderson*, 1956; *Nyquist & Öwall*, 1968, and others). The results of these investigations are difficult to compare, because the measurements were made with different apparatuses and under different experimental conditions. With regard to these facts, it is difficult to analyze earlier reports of loads measured on healthy or pathologically changed teeth.

Different factors seem to influence bite force. In the current literature it is often pointed out that the periodontal membrane is the limiting factor for maximal bite force owing to its pressure and pain receptors (*Black*, 1895; *Perry & Harris*, 1954; *Kraft*, 1962, a.o.). By training, however, the bite force can be considerably increased (*Anderson & Picton*, 1958; *Brekhus, Armstrong & Simon*, 1941, and *Worner & Anderson*, 1944). Male Eskimos with extremely hard-chewed food had a bite force of about 140 kg of the molars with a maximum of about 160 kg (*Jenkins*, 1966), whereas male citizens of the USA had a bite force of the first molar of about 50 kg (*Brekhus, Armstrong & Simon*, 1941). Some results indicate that not only the muscles are influenced by masticatory training, but also the periodontal membrane

Received for publication, December 13, 1969.

and the alveolar bone. Thus Coolidge found in 1937 that the average thickness of the periodontal membrane of teeth with strong bite force was about 0.18 mm. The periodontal membrane of teeth without antagonists had an average thickness of circa 0.13 mm.

To obtain information about the significance of the muscle force for maximum bite force we considered it to be of interest to compare bite force with muscle force of various muscles of the body. If the maximum bite force was mainly depending on the force of the masticatory muscles, one might expect a correlation between maximum bite force and maximum muscle force in other muscle groups than masticatory muscles in the same way as the maximum force of muscles of the body are positively correlated with one another (*Lindegård*, 1953). It might also be expected that maximum bite force would covariate with anthropomethric data such as height, weight, and width of the wrist, because general muscle force is positively correlated to these body characteristics (*Lindegård*, 1953; *Asmussen & Heelbøll-Nielsen*, 1961).

We also found it of interest to investigate the bite force in per cent of the maximum bite force when the subjects were instructed to produce »strong» and »very strong» bite force respectively. The intention was to compare these relationships with the corresponding relationships of other muscles of the body, and also to make it possible to predict a person's maximum bite force from measurements of submaximal bite force in the practical use of bite force measurements, for example in different pathological states.

MATERIAL AND METHODS

Students and student nurses at the School of Dentistry, Umeå university, (58 males and 14 females) 18 to 31 years of age were examined. They were selected from a larger group of healthy individuals. At a clinical-odontological and X-ray examination they did not show pathological changes of the jaws and surrounding tissues, except smaller fillings of the teeth. Some anthropometric data for the male and female group are given in Table I.

Before the examination the subjects made preliminary trials in order to adapt themselves to the equipment used for bite force measurements. They were told to produce the maximum bite force for about 3 sec. The bite force of each of the first pair of molars and of the premolars was measured separately for the left and right side of the jaw. In a fraction of the subjects the bite force of the two medial pairs of incisives was measured. Three measurements were made with each pair of teeth or tooth groups for each type of examina-

Table I.

Mean ($\bar{x}$) and standard deviation (S.D.) of anthropometric data and maximum muscle force of some muscle groups. n = number of subjects examined

Variable	males			females		
	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
Age, years	58	22.6	3.0	17	19.8	1.47
Height, cm	58	175	9.9	17	164	4.9
Weight, kg	58	68.3	12.2	17	56.0	5.86
Femoral condylar width, cm	58	9.4	0.62	17	8.7	0.53
Wrist width, cm	55	5.6	0.46	14	5.1	0.31
Ulnar length, cm	55	27.2	1.85	14	24.9	1.00
Trunk forward flexion force, kg	58	56.0	18.8	14	33.5	4.58
Neck forward flexion force, kg	58	13.2	4.66	14	8.2	2.75
Elbow flexion force, kg	58	25.7	7.19	14	16.6	2.57
Hand-grip force, right, kg	57	45.3	12.0	14	29.1	5.72
Hand-grip force, left, kg	57	40.4	11.1	14	25.5	3.57

tion and the highest value of bite force was taken as the maximum voluntary bite force.

In some individuals it was not possible to perform all assessments, particularly in case of bite of bite force measurements of the medial incisives. This depended partly on the exclusion of individuals with fillings in the incisives, partly due to reluctance to exposing the incisives to maximal load. In the majority of the subjects the maximum bite force and the bite force that was produced by the subjects when instructed to make a »powerful» and a »very powerful» bite were measured in varying order on the same occasion.

All bite force measurements were carried out by the same experimental leader. The bite force values achieved can be considered as representative only for the conditions of the investigation, as the bite force, among other things, is influenced by the object between the teeth, its hardness and height (*Black*, 1895; *Boos*, 1940; a.o.).

Apparatus for measurement of bite force. The bite force dynamometer used is shown in Fig. 1. One of the ends of two steel bars, $15 \times 15 \times 155$ mm, were formed to two plates of about $15 \times 15 \times 2$ mm, with rifled bite areas. The other ends of the steel bars were joined by a wedge formed steel part. Strain gauges were applied to the steel bars. With the strain gauges connected in a Wheatstone bridge and a potentiometer writer (Philips nr D 3878) it was possible to record the load on the bite plates. The equipment was cali-

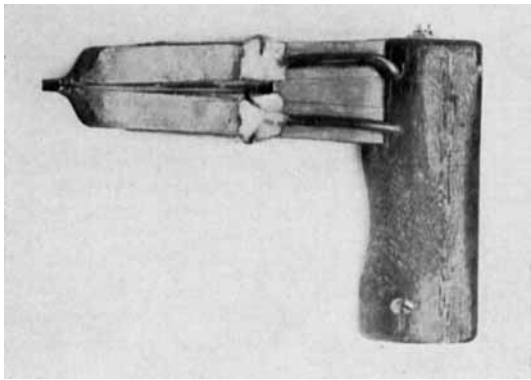

Fig. 1. Apparatus for measurement of bite force.

brated with known loads, and a linear relation between the load and the deviation of the potentiometer writer was obtained. The magnitude of the deviation was independent of the load being applied centric or excentric on the bite plates. The calibration of the apparatus was repeated during the course of the investigation.

The bite plates were covered with a layer of gutta-percha, and on the gutta-percha plated areas the bite force was applied. The layer of gutta-percha was adjusted with a knife in order to get a load only on the teeth to be examined. The distance between the bite areas was about 4 mm, and even at maximal bite force the distance between the plates was only reduced by about 1 mm. Bite force is thus determined under essentially isometric conditions. The bite force was applied in the centric occlusion of the molars and premolars with the incisors in the edge-to-edge position, the mandible being thus in a well reproducible position. This is of great importance, as the position of the mandible, among other facors, influences the magnitude of the bite force (*Carlsöö*, 1956; *Leff*, 1966).

The methodological error of a single bite force measurement has been calculated from double determinations using the second and the third bite force assessments in a series of measurements (Table II).

Measurement of the force of the hand-grip, the flexion of the elbow, trunk and neck. In connection with the assessments of bite force the maximum voluntary isometric force of the hand-grip, the flexion of the elbow, and the forward flexion of the neck and trunk were also investigated. The subjects were also, as in the measurements of bite force, instructed to produce muscle contractions that they perceived as »strong» and »very strong». The highest recorded muscle force was used as a measure of maximal force.

Table II.

Methodological error of bite force measurements estimated from double determinations

Condition	n	Coefficient of variation v % molars	premolars
Maximum bite	48	4.1	6.1
Very powerful bite	35	6.5	5.9
Powerful bite	35	5.2	7.2

The apparatus used for these measurements was described by *Asmussen, Heelbøll-Nielsen and Molbech* (1959). The dynamometers consisted of steel bars with strain gauges connected to a Wheatstone bridge. The same type of potentiometer writer was used as for the bite force assessments. When measuring the force of the hand-grip the distance between the outer edges of the steel rods of the dynamometer was adjusted to correspond to 1/3 of the distance from the third finger tip to the tubercle of the major multangulus bone. The force of the flexion of the elbow was measured with the subjects seated and with the over-arm on a horisontal table. The supinated under-arm was placed at right angles to the over-arm and fixed to the dynamometer with a leather strap round the wrist. The other measurements were made in accordance with the description by *Asmussen, Heelbøll-Nielsen and Mobech* (1959). The dynamometers were calibrated with known weights at regular intervals during the investigation. Thirtyone males and 14 females were investigated by the same experimental leader and the rest by another leader.

RESULTS

The means of the maximum isometric bite force values of the teeth and the tooth groups investigated were a little higher for males than for females (Table III). The differences, however, between men and women were not statistically significant. The men had a considerably greater muscular force than that of the women in the examined muscle groups of the arm, neck and trunk and these differences were statistically significant (Table I).

Table IV shows the coefficients of correlation between anthropometric data, muscle force and bite force respectively in 48 males. In all these subjects the measurements were performed on one occasion. Positive correlations were obtained for many of the relationships between height, weight, and

Table III.

Mean ($\bar{x}$) and standard deviation (S.D.) of maximum voluntary bite force (kg) for the first molars, the premolars and the medial incisives, of submaximal bite force for molars and premolars on instruction to bite »powerfully» or »very powerfully», and of mean differences ($\bar{D}$) between males and females. The mean differences are not statistically significant

	males			females			$\bar{D}$
	n	$\bar{x}_1$	S.D.	n	$\bar{x}_2$	S.D.	$\bar{x}_1 - \bar{x}_2$
Maximum bite force							
Molars	57	49	12.4	14	43	9.3	+6
Premolars	58	41	13.9	14	35	8.7	+6
Incisives	16	22	10.8	14	20	6.2	+2
Very powerful bite force							
Molars	45	40	10.0	14	37	8.7	+3
Premolars	46	33	10.9	14	29	10.2	+4
Powerful bite force							
Molars	57	36	12.9	14	30	7.0	+6
Premolars	58	29	12.0	14	25	9.8	+4

width of the wrist on one side and force of flexion of trunk and neck, elbow flexion and hand-grip force on the other. The muscle force of the various muscle groups were positively correlated with one another. There was, however, no correlation between the results of the above mentioned measurements and the bite force.

Table V shows the bite force in per cent of the maximum bite force, when the subjects were instructed to bite »powerfully» and »very powerfully» respectively. These measurements of submaximal bite force covariate strongly with the maximum bite force (Table VI).

DISCUSSION

The results indicate that the maximum isometric bite force in adults does not, or only slightly, covariate with muscle force of the body muscles or with anthropometric data such as height, weight, width of the wrist (skeletal dimensions). The material examined is, however, rather small and homogenous. It should be mentioned that a similar investigation in 79 children 12 years of age, examined with the same technique as described in the present paper, showed a slight but statistically significant positive correlation between bite force and muscle force, as well as between bite force and skeletal

Table IV.

Linear correlation coefficients (r) for product moment correlations between some anthropometric data, maximum muscle force of some body muscle groups and bite force respectively from 48 males

		1	2	3	4	5	6	7	8	9
Height, cm	1									
Weight, kg	2	0.67***								
Wrist width, cm	3	0.58***	0.59***							
Trunk forward flexion force, kg	4	0.26	0.55***	0.13						
Neck forward flexion force, kg	5	0.20	0.04	—0.10	0.59***					
Elbow flexion force, kg	6	0.14	0.44**	0.27	0.27	0.27				
Hand grip force, left	7	0.44**	0.39**	0.36*	0.51***	0.29*	0.22			
Hand grip force, right	8	0.58***	0.50***	0.26	0.41**	0.17	0.29*	0.73***		
Bite force, premolars, kg	9	—0.16	—0.04	—0.11	0.11	0.18	—0.04	0.13	0.10	
Bite force, first molars, kg	10	—0.01	—0.02	—0.02	0.10	—0.05	—0.15	0.16	0.23	0.67***

Table V.

Powerful and very powerful bite force and isometric muscle force of some muscle groups in per cent of maximum force

	Males n = 57		Females n = 14	
	powerful	very powerful	powerful	very powerful
Premolars	71.6	88.3	74.5	88.2
First molars	71.0	87.9	79.4	84.6
Elbow flexors	76.1	88.6	63.8	83.8
Handgrip, right	82.6	93.9	82.6	89.1
Handgrip, left	92.8	93.4	83.2	89.3

Table VI.

Correlation coefficient (r) for the relationships between maximum and submaximal bite force. The submaximal bite force was measured after instruction to the subjects to bite »powerfully» or »very powerfully». Thirtione males were examined. $P < 0.001$ *for* $r > 0.56$.

	r
Premolars	
Powerfully	0.74
Very powerfully	0.89
Molars	
Powerfully	0.63
Very powerfully	0.82

dimensions (*Linderholm, Lindqvist, Ringqvist & Wennström*, 1971). In any case bite force does not seem to be closely related to the general muscle force and skeletal dimensions of the individual.

Similar diet and masticatory habits may be an explanation of the fairly similar maximum bite force in adult males and females, as well as in children (*Linderholm et al.*, 1971) in spite of differences in general muscle force between these groups. The bite force values found in this investigation are of the same magnitude as those achieved earlier with similar methods of investigation (*Morelli*, 1928; *Andersson*, 1956) but differences between males and females in these earlier investigations were rather more apparent. *Brekhus, Armstrong and Simon*, (1941) thus found a bite force of 54 kg for males and 35 kg for females. Eskimos, too, showed a considerable difference in bite force between males and females (*Jenkins*, 1966).

Masticatory training that increases the bite force (*Jenkins*, 1966) does not only influence the muscles. *Coolidge* (1937) showed that the periodontal membrane is thicker for teeth used at high bite force than for teeth used at a low one. *Jenkins* (1966) considers it possible that maximum bite force is determined both by the masticatory muscles and the periodontal membrane and other parts of the masticatory organ (*Nagle & Sears*, 1958).

The results do not seem to allow a more precise prediction of bite force from various anthropometric data than from mean values of bite force for males and females. The masticatory habits of the population may influence the bite force more than body dimensions. Therefore normal values for groups with similar masticatory habits ought to be determined, if a more precise prediction is needed, for example for diagnostic aims. Age may also be of importance and a greater variability in age than in the described material would have been desirable. However, it was very difficult to collect a representative material of older individuals locally, as very few old subjects had teeth in good condition.

If the teeth are in a bad condition submaximal values of bite force may be easier to measure. Maximum values can then be calculated from such submaximal ones that are obtained when a subject is instructed to bite »powerfully» and »very powerfully». In the male as well as in the female group the ability to discriminate between powerful, very powerful and maximum bite force seems good. However, it does not seem to be possible to draw any conclusions about limiting factors for maximal efforts from these results or from comparisons with submaximum muscle force of other muscle groups (see Table V).

The method used and the normal values achieved have been useful for instance in estimating bite force of partial dentures in comparison with the remaining teeth, and for evaluation of bite force with complete and partial dentures with regard to technical and anatomical conditions.

SUMMARY

An apparatus and a method for measuring isometric bite force has been described. The bite force of young healthy males (n = 58) and females (n = 14) and its relationship to anthropometric data and isometric muscle force of some muscle groups has been studied.

There was no statistically significant correlation in the material between bite force on the one side and general muscle force, body height, weight and skeletal dimensions on the other. The maximum bite force was about the same for men and women.

There was a strong positive correlation between maximum bite force and submaximal bite force, the latter being obtained when instructing the subjects to produce a »powerful» or a »very powerful» bite force.

RÉSUMÉ

LA FORCE MASTICATRICE ISOMÉTRIQUE ET SES RAPPORTS AVEC LA FORCE MUSCULAIRE ET LA MORPHOLOGIE GÉNÉRALES

Les auteurs ont décrit un appareil et une méthode ayant pour but de mesurer la force masticatrice isométrique. Ils ont étudié la force masticatrice de jeunes individus en bonne santé du sexe masculin (n = 58) et du sexe féminin (n = 14) et ses rapports avec les facteurs anthropométriques et avec la force musculaire isométrique de certains groupes musculaires.

Il n'existait pas dans le matériel étudié de corrélation statistiquement significative entre la force masticatrice d'une part, et, d'autre part, la force musculaire générale, la taille, le poids et les dimensions du squelette. La force masticatrice maximum était à peu près la même dans les deux sexes.

Il existait une forte corrélation positive entre la force masticatrice maximum d'une part, et la force inférieure au maximum obtenue lorsqu'on demandait aux sujets de produire une force masticatrice »puissante» ou »très puissante» d'autre part.

ZUSAMMENFASSUNG

ISOMETRISCHER BISSKRAFT UND DESSEN RELATION ZU ALLGEMEINEM MUSKELKRAFT UND KÖRPERBAU

Ein Apparat und eine Methode sind für Registrierung des isometrischen Kraftes des Bisses beschrieben worden. Der Bisskraft junger gesunden männlichen (n = 58) und weiblichen (n = 14) Versuchspersonen und dessen Relationen zu anthropometrischen Angaben und zu isometrischer Muskelstärke einiger Muskelgruppen sind studiert worden.

In der vorliegenden Material liess sich aber keine statistiche significante Korrelation zwichen Bisstärke einerseits und allgemeiner Muskelstärke, Körperlänge, Körpergewicht und skelettalen Dimensionen anderseits erweisen. Die maximale Bisstärke war ungefähr dieselbe für männliche sowie für weibliche Versuchspersonen. Es lag eine starke positive Korrelation zwichen maximaler und submaximaler Bisstärke vor. Die submaximale Bisstärke erhält man, wenn man die Versuchspersonen instruierte, „kräftig" oder „sehr kräftig", den Biss zu produzieren.

REFERENCES

Anderson, D. J., 1956: Measurement of Stress in Mastication, I. J. Dent. Res. *35:* 664—670.

Anderson, D. J. & D. C. A. Picton, 1958: Masticatory Stresses in Normal and Modified Occlusion. J. Dent. Res. *37:* 312—317.

Asmussen, E., K. Heelbøll-Nielsen, & Sv. Molbech, 1959: Methods for Evaluation of Muscle Strength. Communication from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis. 5. Hellerup, Denmark.

Black, G. V., 1895: An Investigation of the Physical Characters of the Human Teeth in Relation to their Diseases, and to Practical Dental Operations, together with the Physical Characters of Filling Materials. Dent. Cos. *37:* 469.

Boos, R. H., 1940: Intermaxilary Relation Established by Biting Power. J.A.D.A. *27:* 1192.

Brekhus, P. J., W. D. Armstrong & W. J. Simon, 1941: Stimulation of the Muscles of Mastication. J. Dent. Res. *20:* 87.

Carlsöö, S., 1956: Muskelverkan och tuggtryck. Sv. tandläk.-tskr. *5;* 117—128.

Coolidge, G. N., 1966: The Thickness of the Human Periodontal Membrane. J. Amer. Dent. Ass. *24:* 1260.

Jenkins, G. N., 1966: The Physiology of the Mouth. S. 413—441. Blackwell Scientific Publications Oxford. 3rd ed.

Kraft, E., 1962: Über die Bedeutung der Kaukraft für das Kaugeschehen. Zahnärztl. Praxis. p. 129.

Leff, A., 1966: Gnatodynamics of four mandibular positions. J. Prosth. Dent. *5;* 844—847.

Lindegård, B., 1953: Variation in Human Body-Build. Acta Psychiatrica et Neurologica. Suppl. *86:* 99—104.

Linderholm, H., B. Lindqvist, M. Ringqvist, & A. Wennström,: To be published 1971.

Morelli, A., 1928: Über Kaudrucksmessung. Zahnärztl. Rundschau. p. 246.

Nagle, R. J. & V. H. Sears, 1958: Dental Prosthetics. Complete Dentures. p. 111—131. The C. V. Mosby Company, St. Louis.

Nyqvist, G. & B. Öwall, 1968: Masticatory load registrations during function. A metodological study. Odont. Revy. *19:* 45—54.

Perry, H. T. & S. C. Harris, 1954: Role of the Neuromuscular System in Functional Activity of the Mandible. J.A.D.A. *48:* 665—673.

Worner, H. K. & M. N. Anderson, 1944: Biting force measurements on children. Aust. J. Dent. *48:* 1.

Addresses:

H. Linderholm,
The Department of Clinical Physiology,
University of Umeå,
S-901 85 Umeå,
Sweden

A. Wennström,
School of Dentistry,
University of Umeå,
S-901 85 Umeå,
Sweden