Variables Affecting Measurements of Vertical Occlusal Force

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Previous studies of occlusal force have provided conflicting results. The purpose of these studies was to determine whether the extent of vertical opening, contralateral occlusal support, or head posture influenced vertical occlusal forces during swallowing, simulated chewing, and maximum biting effort.

Three samples of subjects with normal vertical facial proportions — one each of children, adolescents, and young adults — were evaluated to determine the effects of changes in small (2.5 vs. 6.0 mm) vertical separation of the first molars. A sample of young adults was used to evaluate changes in large (10-40 mm) vertical openings, and a sample of adolescents was used to investigate the effect of contralateral support and head posture. All between-group comparisons were evaluated using non-parametric statistics.

For the small vertical openings, there was significantly more vertical occlusal force at 6.0 than 2.5 mm in children during swallowing and chewing but not during maximum biting effort. In adults, there was significantly more force during swallowing at 6.0 than at 2.5 mm separation, but no differences in chewing or maximum biting. Increasingly large vertical openings resulted in a progressive increase in maximum bite force to a maximum at about 20 mm, followed by a decrease and then a second increase to near-maximum force at about 40 mm for young adults. There were no significant differences in vertical force with or without contralateral support or between flexed, normal, and extended head postures at either of the small openings.

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Introduction.

Investigations of vertical interocclusal force in humans began over 300 years ago (Uhlig, 1953). The force-measuring devices have progressed with technology and presently range from spring and hydraulic devices that are compressed for registration of force, to quartz and foil transducers that operate on the piezo-electric principle. Attempts have been made to relate occlusal forces to the type of anterior occlusion (Garner and Kotwal, 1973), vertical facial type (Taylor, 1936), muscle fiber type (Ringqvist, 1978), and electromyographic activity (Ahlgren and Owall, 1970). The results have been inconsistent and conflicting, which has confused rather than clarified the relationships between occlusal forces and the selected independent variable.

These inconsistent results seem to be due to lack of control of variables that may affect occlusal forces. The age and sex of the subject (Helkimo *et al.*, 1977) and the attitude of the investigator (Molin, 1972) are variables that have been shown to influence occlusal force measurements. It is generally recognized that other factors that need to be controlled are the state of the dentition (Helkimo *et al.*, 1977), the position of the transducer in the mouth (Throckmorton *et al.*, 1980), and vertical facial morphology (Ingervall and Helkimo, 1978). Additional factors that may influence occlusal force data are the extent to which the teeth and jaws are separated when the measurements are made, whether the force is exerted unilaterally or bilaterally, and the patient's head posture during the measurements.

Early occlusal force studies employed bulky instruments that required wide separation of the teeth and jaws. There has been speculation that the extent of vertical separation of the teeth and jaws and especially opening beyond the freeway space may have an effect on the magnitude of occlusal forces (Boos, 1940). This viewpoint has been supported theoretically by length-tension curves for a single muscle fiber. As a muscle fiber is stretched beyond its resting length, more force is generated up to a point; then further stretch results in reduced force generation (Gordon *et al.*, 1964). If the elevator muscles of the mandible behaved like an ideal single fiber, small increases in vertical opening past rest position should increase occlusal forces, whereas larger openings should cause a reduction in occlusal force. Traditional length-tension curves may not be adequate to represent forces generated by the muscles of mastication in occlusal force studies, since *in vivo* forces are produced by a combination of whole muscles (Thexton and Hiimaee, 1975). In some animals, maximum force is generated at or very near maximum opening (MacKenna and Turker, 1975). Vertical occlusal forces in humans need to be measured over a complete range of vertical openings to determine whether the degree of vertical opening has an effect.

Occlusal forces during swallowing are produced by light bilateral occlusal contact at the normal vertical dimension. In contrast, chewing and maximum biting are most often unilateral at a slightly increased vertical dimension. Pruim (1979) noted that unilateral occlusal force measurement could result in asymmetric loading of the temporomandibular joints and inhibition of muscle activity. Since most occlusal force measurement has been accomplished unilaterally without support for the contralateral side of the occlusion, occlusal forces need to be measured with and without contralateral support to evaluate the validity of unilateral force measurement techniques.

Head posture has been shown to influence the pressure placed on the dentition by the musculature and soft tissue (Archer and Vig, 1985). Head posture has also been related to bite opening, in that increased vertical opening leads to extension of the head, possibly so that occlusal forces may be reduced (Daly *et al.*, 1982). Therefore, alterations in head posture, or a combination of alteration in head posture and bite opening may affect occlusal force values.

The purpose of these studies was to test the influence of the amount of molar and jaw separation, supported *vs.* non-supported contralateral occlusion, and head posture on the vertical occlusal forces generated during swallowing, chewing, and maximum biting effort, using reliable and accurate modern transducers.

Materials and methods.

Vertical occlusal forces at small vertical opening (2.5 mm and 6.0 mm). — These were evaluated in three samples of subjects of varying ages. The first sample consisted of 17 children, nine males and eight females, from 6 to 12 years old (mean, 9.3 years), with normal vertical facial proportions. Oc-

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clusal forces were measured on five different occasions over a 1½-year period, which provided data for 80 bite-recording sessions for these subjects. There were no longitudinal changes for this age group, so that data were pooled. The second sample consisted of ten adolescents, six females and four males, aged from 11 to 15 (mean, 13.1 years), with normal vertical facial proportions. This group had recordings on one occasion. The third sample of 21 young adults, nine males and 12 females, aged from 24 to 35 (mean, 26.9 years), with normal vertical facial proportions, also had occlusal forces recorded on one occasion. This group was previously reported by Proffit *et al.* (1983) and is included here so that the effects of age can be assessed across the groups. The method and validity of the appraisal of vertical facial proportions in terms of cephalometric variables have been reported previously (Fields *et al.*, 1984).

All subjects had measurements made of their vertical occlusal forces during swallowing, chewing, and maximum biting effort at two levels of jaw opening. At the 2.5-mm permanent first molar separation, we used a transducer fabricated in our laboratory. This transducer incorporates a 30-μm-thick sheet of poly (vinylidine fluoride) (Kreha Corp., Tokyo, Japan) as the active element within a small stainless steel casing. At the 6.0-mm molar separation, we used a commercially available quartz crystal transducer (Kistler Corp., New York). The signals produced by distortion of the piezo-electric element in the transducer were processed through a charge amplifier and displayed on an oscilloscope.

The transducers were positioned on the distobuccal cusp tip of the lower first molar parallel to the occlusal plane and supported in a matrix of composite resin. A silicone rubber matrix was added to guide jaw position. Forces during swallowing were recorded by placing 2 ml of water into patients' mouths, asking them to swallow the water, and then recording occlusal forces when the patients swallowed again upon command, immediately after swallowing the water. Forces during simulated chewing were then recorded by asking the subjects to "chew with the same force you would use chewing steak". The last step was to record maximum biting force. Additional details regarding transducer fabrication, mounting, reliability, and accuracy have been reported (Proffit *et al.*, 1983).

Vertical occlusal forces at larger vertical openings. — These were studied in eight young adult males (from 25 to 29 years of age) by examining only maximum biting force, because simulated chewing is difficult and swallowing almost impossible at the wide openings. Vertical occlusal force was measured at 5-mm increments from 10 to 40 mm of incisor separation. Ten millimeters of incisor separation generally exceeded the 6 mm of molar separation in the small vertical opening studies; the 10-ml opening was chosen as being the smallest. The quartz transducer was mounted as previously described, and the vertical occlusal dimension was increased by addition of restorative resin to the transducer matrix. The reliability of repeated measures was within 20% of the initial force value.

The effect of supported vs. non-supported contralateral occlusion. — This was evaluated in the sample of 10 adolescents using both types of transducers and 2.5-mm and 6.0-mm molar separation. In the supported condition, the bite block with the transducer and a silicone support block for the contralateral side were both used. In the non-supported condition, only the bite block with the transducer was used.

The effects of changes in head posture. — This was examined using the same sample of 10 adolescents. Occlusal forces were measured for each subject in natural head position and at positions 20 degrees flexed (chin down) and 20 degrees extended (chin up) from natural head position. Natural head position was determined by having each subject look at a landmark on a distant wall, take one step forward, and achieve a comfortable head posture while looking at the distant landmark (Showfety *et al.*, 1983). A leveling device was attached to the head in natural head position and zeroed so that the flexed and extended head postures could be accurately determined.

For all studies, each type of vertical occlusal force was measured five times at each vertical opening. All subjects were instructed using a standard protocol to eliminate investigator influence. Pair-wise comparisons were made with the Wilcoxon signed rank test because of non-normal distributions and unequal variances, and the alpha level was set at 0.01.

Results.

Small vertical openings. — The data in Table 1A illustrate the children's pooled mean vertical occlusal force for all visits, each function, and each opening. The vertical forces during swallowing and chewing were significantly greater ($p \leq 0.01$) at 6.0-mm molar than at 2.5-mm molar separation. Although increased bite opening tended to generate greater vertical occlusal forces in adolescents, there were no significant differences between the 2.5- and the 6.0-mm molar separations for the adolescents during any of the occlusal functions (Table 1B). There was significantly greater vertical occlusal force at 6.0-mm openings for the normal young adults during swallowing, but for no other functions (Table 1C).

Large vertical openings. — Analysis of the data in Table 2 indicates that the mean vertical occlusal force increased initially with opening to 20 mm, then decreased until 30 mm of opening was reached and increased again as opening became

TABLE 1

A. MEAN VERTICAL OCCLUSAL FORCE (kg) FOR 6-12-YEAR-OLD CHILDREN (n = 17)

	Vertical Opening			
	2.5 mm		6.0 mm	
	Mean	(S.D.)	Mean	(S.D.)
Swallowing	1.94	(2.49)	2.60	(2.53) *
Chewing	7.23	(6.30)	10.18	(6.02) *
Maximum Force	14.47	(12.66)	15.20	(10.38)
B. MEAN VERTICAL OCCLUSAL FORCES (kg) FOR ADOLESCENTS (n = 10)				
Swallowing	1.8	(1.6)	3.0	(2.3)
Chewing	7.3	(3.9)	9.0	(5.8)
Maximum Force	14.5	(7.5)	16.1	(8.5)
C. MEAN VERTICAL OCCLUSAL FORCES (kg) FOR YOUNG ADULTS (n = 21)				
Swallowing	2.9	(3.7)	4.8	(4.8) *
Chewing	13.5	(10.4)	16.2	(13.8)
Maximum Force	31.0	(20.0)	35.6	(18.7)

*Differences between openings significant at $p \leq 0.01$ level.

TABLE 2

MEAN MAXIMUM BITE FORCE (kg) AT LARGE OPENINGS (n = 8)

Opening (mm)	Mean	(S.D.)
10	9.6	(7.7)
15	13.5	(10.3)
20	17.6	(7.1)
25	14.5	(7.6)
30	10.4	(5.8)
35	12.3	(6.9)
40	14.3	(6.7)

greater. All patients showed two peaks of occlusal force, with some variability in their precise location.

Supported vs. non-supported contralateral occlusion. — Analysis of the data in Table 3 indicates that, although mean forces were slightly larger with both sides supported, there were no significant differences between the supported and the non-supported conditions for either vertical opening.

Head posture. — Analysis of the data in Table 4 indicates that flexing or extending the head did not significantly affect the vertical occlusal force for any of the occlusal functions at either opening. Changing head posture, however, did produce differences in occlusal force between the 2.5- and 6.0-mm transducers. When the head was flexed, significantly greater vertical occlusal force was apparent at the 6.0-mm vertical opening than at the 2.0-mm opening for swallowing and chewing ($p = 0.008$ and 0.004, respectively). For maximum biting force, the difference approached significance ($p = 0.02$). Although greater force was often generated at 6.0 mm when the head was extended, the differences were not statistically significant.

Discussion.

Analysis of these data indicates significantly greater vertical occlusal forces at the 6.0-mm than at the 2.5-mm opening during swallowing and chewing (but not for maximum biting) for normal children. On the other hand, the data for normal adolescents and adults showed no significant differences in vertical force between the 2.5- and 6.0-mm openings except during swallowing in the adults. The considerable variability between subjects is reflected in the large standard deviations, and this made it difficult to demonstrate significant differences. These data, as a group, indicate that the age of the subject may be a confounding variable when different vertical openings of under 6 mm are employed during data collection. Small changes in jaw separation and muscle stretch in children may be significant on a proportionate basis, because the resting muscle length is much smaller, while the same absolute changes are trivial in larger adolescents and adults. Therefore, even small vertical openings should be documented and controlled when occlusal forces in children are being evaluated.

TABLE 3
MEAN VERTICAL OCCLUSAL FORCES (kg) FOR THE SUPPORTED AND NON-SUPPORTED CONDITIONS (n = 10)

	Opening (mm)	Supported Mean (S.D.)	Non-supported Mean (S.D.)
Swallowing	2.5	1.7 (1.8)	1.8 (1.6)
	6.0	3.2 (3.5)	3.0 (2.3)
Chewing	2.5	8.9 (7.7)	7.3 (3.9)
	6.0	11.5 (4.6)	9.0 (5.8)
Maximum Force	2.5	15.0 (8.3)	14.5 (7.5)
	6.0	17.7 (7.4)	16.1 (8.5)

TABLE 4
MEAN VERTICAL OCCLUSAL FORCES (kg) AT SELECTED HEAD POSTURES (n = 10)

		Head Posture		
		Flexed	Natural	Extended
	Opening (mm)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Swallowing	2.5	2.1 (2.2)	1.8 (1.6)	1.8 (1.6)
	6.0	4.1 (3.1)	3.0 (2.3)	5.1 (4.2)
Chewing	2.5	8.3 (4.2)	7.3 (3.9)	7.1 (4.4)
	6.0	13.1 (6.5)	9.0 (5.8)	11.1 (7.1)
Maximum Force	2.5	14.3 (7.5)	14.5 (7.5)	12.7 (6.4)
	6.0	21.8 (9.6)	16.1 (8.5)	20.3 (8.3)

Vertical occlusal forces at large openings do not increase to a single peak then decline, as might have been predicted from a conventional length-tension curve. Neither do they decrease consistently as would be predicted by calculations of mechanical advantage if muscle activity were constant. By the Throckmorton *et al.* (1980) model, increasing mandibular opening and maintaining the transducer position on the permanent mandibular first molar leaves the moment arm of bite force and the temporalis muscle unchanged. Therefore, the mechanical advantage of the temporalis muscle is unchanged. By contrast, the moment arm of the masseter muscle (which is at a right angle to the force vector constructed from gonion to the intersection of the frontal and squamous portions of the zygomatic bone) decreases as the mandible rotates open. This occurs because the angle of the mandible moves backward and away from the fixed point on the zygoma. This consistently decreases the mechanical advantage of the masseter muscle and therefore could decrease bite force.

Likewise, as the mandible rotated open, the incidence angle of force applied to the piezo-electric crystal decreased, because we maintained the transducer position parallel to the occlusal plane. This had the potential to reduce the electric signal and the recorded vertical occlusal force. Therefore, both the decreasing of mechanical advantage of the masseter and the geometry of force vectors applied to the piezo-electric crystals should contribute to consistently decreasing occlusal forces at the larger openings, instead of the observed pattern with two peaks. Obviously, these effects were overcome at large openings.

The shape of the occlusal force curve may be due in part to the fact that the force is produced by multiple whole muscles whose individual fibers have different length-tension characteristics. In addition, the mandibular elevator muscles have several predominant fiber orientations so that different groups of muscle fibers are optimally positioned at varying amounts of jaw separation. Another explanation for the distinctive curve is that the visco-elastic stretch of the muscles and facial soft tissues contributes to the second peak in occlusal force activity at extreme openings. Large openings definitely alter occlusal forces in a non-linear manner and should be controlled in occlusal force studies.

For subjects in the adolescent age group, contralateral support of the mandible did not appear to cause significant alteration in the vertical occlusal force recorded at the first molar. The supported condition, which might be expected to distribute the force more evenly, did not reduce the vertical occlusal force but slightly increased it, particularly during chewing. Muscular balancing of the mandible presumably stabilizes it when force transducers are placed on only one side, just as it does during normal function. Contralateral support does not appear to have a significant effect on vertical occlusal forces.

At a given opening, during a specific activity, changes in head posture did not significantly alter vertical occlusal force. It was surprising that, with the head in the flexed position, adults did have larger occlusal force with 6.0-mm molar separation than at 2.5-mm, and even more surprising that when flexion produced an increase, extension tended to do the same thing. We presume that these effects relate to a change in orientation and/or activity of the depressor muscles of the mandible, since head posture does not directly affect the elevator muscles. When the elevator muscles contract to create vertical occlusal forces, the depressor muscles (and the other soft tissues of the neck) produce some resistance. Flexion, it appears, decreases this resistance more when the molars are separated 6.0 mm than when the separation is near the usual postural position, while extension fails to increase it and may also facilitate biting at the wider separation.

In summary, analysis of these data demonstrates that experimental measurements of vertical occlusal force are not affected by whether the jaw is supported bilaterally or has all the force on one side. The amount of separation of the teeth when the measurements are made is important: in children, at small vertical openings; and in adults, beyond 6.0-mm molar separation (and perhaps at smaller openings, despite our failure to show statistically significant differences). Head posture must also be controlled because of its interaction with the amount of jaw (tooth) separation.

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REFERENCES

AHLGREN, J. and OWALL, B. (1970): Muscle Activity and Chewing Force: A Polygraphic Study of Human Mandibular Movements, *Arch Oral Biol* 15:271-280.

ARCHER, S. and VIG, P. (1985): Effects of Head Posture on Intra Oral Pressure in Classes I, II and III Adults, *Am J Orthod* 87:311-318.

BOOS, R.H. (1940): Intermaxillary Relation Established by Biting Power, *J Am Dent Assoc* 27:1192-1199.

DALY, P.; PRESTON, C.B.; and EVANS, W.G. (1982): Postural Response of the Head to Bite Opening in Adult Males, *Am J Orthod* 82:157-160.

FIELDS, H.W.; PROFFIT, W.R.; NIXON, W.L.; PHILLIPS, C.; and STANEK, E. (1984): Facial Pattern Differences in Long-Faced Children and Adults, *Am J Orthod* 85:217-223.

GARNER, L.D. and KOTWAL, N.S. (1973): Correlation Study of Incisive Biting Forces with Age, Sex, and Anterior Occlusion, *J Dent Res* 52:698-702.

GORDON, A.M.; HUXLEY, A.F.; and JULIAN, F.J. (1964): The Length-Tension Diagram of Single Vertebrate Striated Muscle Fibres, *J Physiol Lond* 171:28-30.

HELKIMO, E.; CARLSSON, G.E.; and HELKIMO, M. (1977): Bite Force and State of Dentition, *Acta Odontol Scand* 35:297-303.

INGERVALL, B. and HELKIMO, E. (1978): Masticatory Muscle Force and Facial Morphology in Man, *Arch Oral Biol* 23:203-206.

MacKENNA, B.R. and TURKER, K.S. (1975): Twitch Tension in the Jaw Muscles of the Cat at Various Degrees of Mouth Opening, *Arch Oral Biol* 23:917-920.

MOLIN, D. (1972): Vertical Isometric Muscle Forces of the Mandible, *Acta Odontol Scand* 19:563-568.

PROFFIT, W.R.; FIELDS, H.W.; and NIXON, W.L. (1983): Occlusal Forces in Normal and Long-face Adults, *J Dent Res* 62:566-570.

PRUIM, G.T. (1979): Asymmetrics of Bilateral Static Bite Forces in Different Locations on the Human Mandible, *J Dent Res* 58:1685-1687.

RINGQVIST, M. (1978): Histochemical Studies of the Human Masseter Muscle. In: **Muscle Adaptation in the Craniofacial Region**, Monograph #8, Craniofacial Growth Series, D.S. Carlson and J.A. McNamara, Eds., Ann Arbor, MI: Center for Human Growth and Development, pp. 247-250.

SHOWFETY, K.; VIG, P.; and MATTESON, S. (1983): A Simple Method for Taking Natural-Head-Position Cephalograms, *Am J Orthod* 83:495-500.

TAYLOR, A.T. (1936): A Study of the Incidence and Manifestations of Malocclusion and Irregularity of the Teeth, *Dent J Aust* 8:285-293.

THEXTON, A.J. and HIIMAEE, K.M. (1975): The Twitch-Contraction Characteristics of Opposum Jaw Musculature, *Arch Oral Biol* 20:743-748.

THROCKMORTON, G.; FINN, R.; and BELL, W. (1980): Biomechanics of Differences in Lower Face Height, *Am J Orthod* 77:410-420.

UHLIG, H. (1953): Über die Kaukraft, *Dtsch Zahnarztl Z* 8:30-45.