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 — each one 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.


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 Hildreth, 1975). In some animals, maximum force is generated at or very near maximum opening (MacKenna and Turk, 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. Pruijn (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 Vign, 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-
Vertical occlusal 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 (vinylidene 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 effects 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 ≤ 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) |
|-----------------|--------|--------|--------|
|                | 2.5 mm | Vertical Opening | 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 ≤ 0.01 level.

### TABLE 2

<table>
<thead>
<tr>
<th>MEAN MAXIMUM BITE FORCE (kg) AT LARGE OPENINGS (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening (mm)</td>
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<tr>
<td>--------------</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
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<tr>
<td>25</td>
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<tr>
<td>30</td>
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<tr>
<td>35</td>
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<td>40</td>
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forces
All
Analysis
no
variability
subjects
differences in
either
flexing
head
occlusal
ing
(p
opening
Discussion.

for normal children.
adolescents and adults
Maximum
Swallowing
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SUPPORTED

6.0 21.8
(N)

VERTICAL OCCLUSAL FORCES

No.

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 chew-
ing (p = 0.008 and 0.004, respectively). For maximum biting
force, the difference approached significance (p = 0.02). Al-
though greater force was often generated at 6.0 mm when the
head was extended, the differences were not statistically sig-
ificant.

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 open-
ings 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 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.

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 mechan-
ical advantage if muscle activity were constant. By the 'Throck-
morton et al. (1980) model, increasing mandibular opening
and maintaining the transducer position on the permanent man-
dibular 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 inter-
section of the frontal and squamous portions of the zygomatic
bone) decreases as the mandible rotates open. This occurs be-
cause the angle of the mandible moves backward and away
from the fixed point on the zygoma. This consistently de-
creases 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, be-
cause 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 de-
creasing of mechanical advantage of the masseter and the ge-
ometry 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 open-
ings.

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 charac-
teristics. 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 oc-
clusal force studies.

For subjects in the adolescent age group, contralateral sup-
port of the mandible did not appear to cause significant alter-
atation 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 sepa-
ration 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 man-
dible, 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 tis-
es 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

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

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

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

<table>
<thead>
<tr>
<th>Opening (mm)</th>
<th>Head Posture</th>
<th>Supported Mean (S.D.)</th>
<th>Non-supported Mean (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swallowing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Flexed</td>
<td>2.1 (2.2)</td>
<td>1.8 (1.6)</td>
</tr>
<tr>
<td>6.0</td>
<td>Natural</td>
<td>4.1 (3.1)</td>
<td>3.0 (2.3)</td>
</tr>
<tr>
<td>Chewing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>8.3 (4.2)</td>
<td>7.3 (3.9)</td>
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</tr>
<tr>
<td>6.0</td>
<td>13.1 (6.5)</td>
<td>9.0 (5.8)</td>
<td>11.1 (7.1)</td>
</tr>
<tr>
<td>Maximum Force</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>14.3 (7.5)</td>
<td>14.5 (7.5)</td>
<td>12.7 (6.4)</td>
</tr>
<tr>
<td>6.0</td>
<td>21.8 (9.6)</td>
<td>16.1 (8.5)</td>
<td>20.3 (8.3)</td>
</tr>
</tbody>
</table>
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


