The Effect of Vertical Dimension and Mandibular Position on Isometric Strength of the Cervical Flexors

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ABSTRACT: This study compared the peak isometric strength of the cervical flexors in deep bite temporomandibular dysfunction (TMD) patients while biting in four bite positions: habitual occlusion, edge-to-edge, lateral shift and retruded. These values were then compared to those of the same subjects' bite positions elevated to a functional criterion (maximum isometric strength of the deltoid muscles). The mean height increase was 2.4 mm with a range of 1.5-3.8 mm. Fifteen of eighteen deep bite subjects met an inclusionary criterion, at least 13.3 Newtons (N) stronger cervical muscle strength with mandible relaxed open than habitual bite. Peak strength biting edge-to-edge was significantly greater than biting in habitual occlusion. Strength was found to increase significantly when biting in each of four mandibular positions when the bite was elevated to the functional criterion. The greatest strength was obtained from elevated habitual and edge-to-edge positions. The findings are of clinical significance, suggesting that cervical muscle isometric strength is affected by bite position and vertical dimension of occlusion. The results suggest that when biting, individuals with deep bite may be functioning at about 60% of their potential cervical flexor, isometric strength. The interaction between occlusal position, vertical dimension and cervical muscle function suggests a craniomandibular-cervical masticatory system.

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In 1977, Stenger[1] proposed that repositioning the mandible in cases where there is a lack of posterior bite support and malocclusion influences muscular function in other parts of the body. This was also put forward by Eversaul[2] at about the same time.

Smith[3] published the first test of Stenger's proposal, judging strength subjectively. Later, he used an electronic strain gauge to measure strength.[4] In both experiments, deltoid strength was found to increase when the bite was elevated. Critics[5-10] stated that the studies lacked proper controls and were not supported by statistical analysis. Forgione, et al.[11] performed the appropriate statistics on Smith's data and confirmed the increase. Smith's reports stimulated a number of studies[5-10,12-22] which, at first glance, supported their contention that strength did not increase with elevated vertical dimension of occlusion.

Forgione, et al.[11] reviewed these studies in an attempt to resolve the conflict in the reported data. They pointed out that: l. Some of the studies used subjects with no apparent malocclusions or missing posterior support,[8,15,17,18,21] while others mixed subjects with different types of occlusion[3,4,6,10,23]; 2. Most bite appliances[5-10,12,15,17,18,20,21,23] were set other than functionally as in Smith's studies, and the contradictory results were

used to criticize Smith's results under the assumption that all bite plates were equivalent; 3. A major source of confusion existed because isokinetic data which showed no strength increase was used by some to criticize the studies of isometric strength that showed strength increase[5,8,10,15,18]; 4. Some researchers employed questionable statistical techniques and used independent groups presuming equivalent baseline strength[6-8,10]; and 5. Some authors explained that the results that supported Stenger's proposal were due to placebo effect[6,10,15,24] even though a placebo effect was not found in their own experiments or in every other study of bite and strength.

Forgione, et al.[11] posited that because muscle movement affects measurable force output, isometric (static) contractions provide a more accurate and reliable assessment of muscle strength. They concluded that when the vertical dimension of a bite plate is set to a height which produces maximum resistance of the deltoid muscles subjectively (a functional criterion) a significant increase in isometric strength occurs when measured objectively. This increase also occurs with a vertical dimension approaching that position.

Forgione, et al.[25] found deltoid isometric strength in a group of subjects with mixed occlusions to be significantly greater with an elevated habitual bite than when biting in either a lateral shift or placebo condition.

A double-blind study by Abduljabbar, et al.[26] found that increasing vertical dimension to a criterion of maximum deltoid isometric strength resulted in a significant increase in isometric strength of extension and flexion of the extremities as well as the shoulder.

Despite criticism voiced by earlier authors, increased isometric strength associated with bite elevating appliances is being recorded in independent laboratories around the world.[27-29]

The literature contains some speculations about the function of neck muscles, head posture and vertical dimension of occlusion,[30-32] but no studies of bite position and cervical muscle strength have, as yet, been published. A clinical study of cervical headaches suggested that a direct relationship exists between forward head posture and weakness with lack of isometric endurance of the upper cervical flexor musculature.[33]

The present study was designed to assess the effect on peak isometric strength of the cervical flexors of deep-bite subjects under four bite positions: l. Habitual occlusion (centric occlusion); 2. Fully retruded (centric relation); 3. Edge-to-edge incisal contact; and 4. A lateral shift position. Strength was measured both with and without lower intraoral appliances, the vertical dimension of which was set to a height which maximized bilateral isometric deltoid strength.

Materials and Methods

Fifteen volunteers (seven men & eight women, ages ranged from 21 to 56 years) were used for the study. Volunteers were solicited from individuals treated at the Gelb Craniomandibular/Orofacial Pain Center at Tufts University School of Dental Medicine, Boston, MA. Only subjects who showed higher peak resistance (at least 13.3 Newtons) with the teeth apart than with the teeth in contact were included in the study. Preliminary study revealed that subjects who did not show a difference of three or more pounds (three pounds equals l3.3 Newtons) tended either to get weaker as the vertical dimension was increased (no sign of loss of vertical dimension initially) or to show very little resistance (bracing in anticipation of pain and appearing to be too weak to participate in the study). Three subjects (one man & two women, ages 21-37 years) were rejected on this basis. In addition, subjects had to meet the following criteria: l. No history of physical trauma to the head and neck; 2. No clicking, grating or popping noises of the cervical vertebrae during neck movement; 3. No chronic illness; 4. No significant limitation in head, neck movement; 5. No tingling or numbness in the head, neck or shoulders; 6. No systemic disease; and 7. Having at least 50% of the mandibular incisors obscured when biting. The choice of deep bite subjects was to provide a homogeneous population with loss of vertical dimension.

Muscle Testing Position

This test position was used both for meeting the inclusion criterion of 13.3 Newton difference between biting and relaxed open mandible and for strength testing in the main experiment. The subject was seated in an erect dental chair with head erect and eyes looking straight ahead. Head position was neutral and relaxed with neck neither extended nor flexed. Shoulders were stabilized during the test by ensuring that the scapulae were in contact with the back of the chair. In this fashion only sternocleidomastoid muscles and other, weaker neck flexors exerted the main resistance to the force which was applied to the forehead. The head rest was adjusted so that there was one inch of space between the rest and the subject's head. This protected the neck from sudden hyperextension due to sudden yielding to the pressure applied.

Subjects were instructed to resist the force to the limits of their strength. Each subject was tested by applying a rapidly increasing horizontal force to the forehead by means of a hand held strain gauge (Kinesiometer, BIO MY Products, Carlsbad, CA). The loading cell, which had a contact surface covered with leather, measured 5.5 cm by 7 cm. Increasing force was applied over a three

second period until resistance was overcome (**Figure 1**). Subjects were tested twice and the two scores averaged in each mandibular position: mandible relaxed open (lips and teeth slightly parted) and mandible in habitual bite. The strain gauge was calibrated by a spring-loaded dynamometer before each subject was tested. A strip-chart recording was made for each variation of output of the strain gauge. This permitted close examination of the slope depicting pressure application over time and served as a control, ensuring that the rate of applied pressure was similar in all trials. The inclusion data are shown in **Table 1**.

Main Experiment

Subjects who met the inclusion criteria were scheduled for a second visit for the first phase of the experiment. In this phase, five lower study casts, one upper cast, face-bow transfers and wax occlusal registrations were obtained. Casts were mounted on a Whip Mix articulator (Whip Mix Corp., Louisville, KY). A face-bow transfer was used to mount the maxillary casts. The mandibular casts were mounted to the maxillary casts using habitual occlusion (maximum intercuspation) as recorded with wax occlusal registration. Four lower bite plates were then fabricated for each subject to get ready for the second phase of testing. Each bite plate was formed by heating hard pressed acrylic disks on a Dentsply Vacupress (Right-Guard Corp. York, PA) and pressure formed on a mandibular model.

Figure 1
Application of transducer to forehead of subject.

Table 1
Peak Isometric Cervical Flexor Strength (Newtons) of the Inclusion Criterion: Mean of Two Trials, Mandible Relaxed Open vs. Habitual Bite

Subject #	Mandible relaxed open (N)	Habitual bite (N)
1	133.2	66.6
2	206.5	128.7
3	109.9	78.4
4	29.9	18.4
5	151.8	102.1
6	148.7	102.1
7	75.4	46.6
8	143.2	83.9
9	114.3	92.1
10	108.8	65.5
11	124.3	92.1
12	157.6	97.7
13	170.9	121.0
14	130.9	83.2
15	93.2	69.2
Mean	**126.6**	**83.2**

$t_{df14} = 9.2$, $p < 0.0001$

During the third visit, four bite plates were constructed and inserted. The first position was constructed to an empirically extended vertical dimension of occlusion by arbitrarily adding acrylic over the posterior occlusal surfaces of the bite plate. The subject was then asked to bite gradually in the habitual path of closure. As the subject bit, the isometric strength of the deltoid muscles of both arms was tested repeatedly until maximum resistance to the isometric deltoid press was achieved (see Forgione, et al.[25]). At this point, the subject was asked to stop biting. If the bite closed beyond the point of maximum deltoid strength (the muscles became weak again), the plate was removed, the partially set acrylic was then remolded to extend the vertical dimension, and the subject was asked to bite gradually again. Equilibration of the bite plate continued until peak resistance to the downward force applied to the wrist of the extended arm of the subject was obtained from each arm. Then the mouthplate was fitted over the mounted lower cast and the incisal guide pin dropped over the occlusal table. This position was thereafter considered the elevated habitual (elevated CO) bite position. The other three positions, edge-to-edge (forward position), retruded (elevated CR) and the shift position were constructed to the same vertical height by adding acrylic resin. The shift position was constructed to shift the bite one mm to the left. Once the mandibular plates were completed on the articulator, polished and

determined to be comfortable to the subject, the subject was scheduled for visit number four, neck muscle testing.

Testing each subject in four positions, with and without the bite plate, comprised the second phase of the study. Two experimenters were involved. The principal investigator fabricated and inserted the plates. The second experimenter (blind to mandibular position) calibrated the strain gauge but was out of the room when plates were inserted and instructions given to subjects. He also applied pressure and recorded results. The eight mandibular positions were tested in a random sequence with a three minute rest between trials. Each mandibular position was tested twice and the average of the two measurements was recorded as the subject's strength score for that position. In this manner, eight measurements were obtained from each subject.

Results

The mean peak strength of the cervical flexors for the 15 subjects in the first phase of the study (the inclusion criterion) was significantly greater with the mandible relaxed open than in habitual occlusion (**Table 1**). The mean isometric strength in the relaxed open position was 52% greater than the strength obtained while biting in habitual occlusion.

A two factor (ABS) factorial, within subject analysis of variance (ANOVA) with both factors related, was used to assess isometric strength of the cervical flexors while biting in four different positions at two vertical dimensions. The "A" factor was biting: l. Without bite plate on natural dentition; and 2. With the bite elevating appliance inserted. The "B" factor was the four mandibular positions: Bl. Habitual; B2. Retruded; B3. Edge-to-edge; and B4. Shift lateral.

The ANOVA (**Table 2**) showed that the overall effect of increasing the vertical dimension (Factor "A") increased the mean strength of all subjects significantly from 96.5 N (SD = 34.3) to 120.7 N (SD = 37.2).

When all scores with and without plates were combined for each of the four mandibular positions and the means of the four mandibular positions were compared (Factor B), they were found not to differ.

Table 3 shows the significant AB interaction. Without the plate, the mean of the edge-to-edge position (102.4 N) was significantly greater than that of the habitual position (89.5 N), but no different from the means of the other positions without a plate. The comparison between means of the elevated positions and means of non-elevated positions showed that the mean of every elevated position was significantly greater than the mean of its respective nonelevated position. Comparisons among the elevated position means showed that the habitual and edge-to-edge means were no different from each other and significantly greater than only the mean of the retruded position. (**Figure 2**). When each position without a plate was compared to each mean of the elevated positions, the means of all elevated positions were found to be significantly greater than the means of the non-elevated positions with one exception. The elevated, retruded mean was not significantly different from that of the edge-to-edge position without a plate.

A percent change from baseline was calculated for each subject for each bite condition as follows: l. The mean peak strength score of the habitual bite (without the plate) was subtracted from the mean peak strength score of every bite position; and 2. Each difference was then divided by the mean strength score of the habitual bite without the plate. Using this formula, subtracting the score of the habitual bite condition without plate from itself produced a value of zero, the baseline. These percent changes from baseline are presented in **Figure 3**. The greatest percent increases were achieved in both the elevated habitual condition (40%) and the elevated edge-to-edge condition (42%).

Setting the height of the bite plate to peak strength of the deltoid muscles resulted in a mean elevation of the bite of 2.4 mm with a range of 1.5-3.8 mm (**Table 4**).

An additional analysis was performed to compare the reliability of the mean peak cervical flexor strength obtained when biting in habitual occlusion. The mean of the inclusion criterion bite in habitual (**Table 1**) and the mean of same subjects biting in habitual occlusion in the main experiment (**Table 3**) were compared. A t-test for paired samples showed that the former, 83.2 N was no different from the latter, 89.5 N, $p > 0.10$ (Pearson $r = 0.85$, $p < 0.01$).

Finally, the mean peak strength obtained with the mandible relaxed open (126.6 N) from the inclusion criterion (**Table 1**), was compared to the mean peak strength obtained when biting in habitual bite at elevated vertical dimension (125.0 N). They were found not to differ, $p > 0.10$ (Pearson $r = 0.81$, $p < 0.01$).

Discussion

The results of this study showed that raising the vertical dimension of deep bite subjects to a point of maximum isometric strength of the deltoid muscles produced a significant increase of isometric strength of the cervical flexors. The increase in cervical flexor strength occurred regardless of bite position. The data of the inclusion criterion show that the relaxed open position appears to approximate the elevated habitual position with respect

Table 2
Summary of ABS ANOVA of Muscle Resistance (Newtons)

Source	DF	SS	MS	F-Ratio	P Level
A	1	17529.4	17529.4	75.6	0.00001
B	3	1721.4	573.8	1.3	0.29
S	14	117400.0	8385.7		
AB	3	1890.6	630.2	3.3	0.03
AS	14	3245.0	231.8		
BS	42	19103.9	454.8		
ABS	42	8077.3	192.3		
Total	119	168967.6			

Simple index of skew: all cells < 20%

Bartlett's test for equality of cell variances:

B chi-square = 0.38	df = 1	p > 0.10
A chi-square = 1.53	df = 3	p > 0.10
AB chi-square = 3.22	df = 7	p > 0.10

Factor A	**Mean**	**SD**	**N**
Without plate	96.5	34.3	60
With plate	120.7	37.2	60

to its effect on cervical flexor, isometric peak strength. It is noteworthy that the mean strength of cervical flexors in habitual bite without a bite plate was the lowest strength score obtained. This low level was found to be reliable, being no different from the data of the inclusion criterion ($r = 0.85$, $p < 0.01$).

In each of the four bite positions (**Figure 2**), strength biting at the elevated vertical was significantly greater than biting without the plate. **Figure 3** illustrates that increases of from 24% to 42% above habitual bite (baseline) were obtained. These results are consistent with those of earlier studies which found that increasing the vertical dimension can maximize isometric strength.[3,4,13,14,25,26]

Table 3
Mean and SD of Same Subjects in Four Bite Positions With and Without Bite Plane.
N = 15 Per Cell. Significant Difference Values in the Mean Strengths
Among the Eight Conditions Are Presented Below the Means
(*Italics* Signify the Elevated Conditions)

A x B	Habitual	Retruded	Edge-to-edge	Lateral Shift
Without bite plane	89.5	98.0	102.4	96.1
Standard Dev.	27.6	32.6	36.0	41.9
With bite plane	125.0	111.1	127.2	119.3
Standard Dev.	38.5	34.3	36.9	40.8

A x B	Habitual	Retruded	Edge-to-edge	Lat. shift	Hab. plate	Ret. plate	Edge plate
Habitual	--------						
Retruded	NS	--------					
Edge to edg.	<0.02	NS	--------				
Lat. shift	NS	NS	NS	--------			
Hab. plate	<0.001	<0.001	<0.001	<0.001	--------		
Ret. plate	<0.001	<0.02	NS	<0.01	>0.01	--------	
Edg. plate	<0.001	<0.001	<0.001	<0.001	NS	<0.01	--------
L.S. plate	<0.001	<0.001	<0.01	<0.001	NS	NS	NS

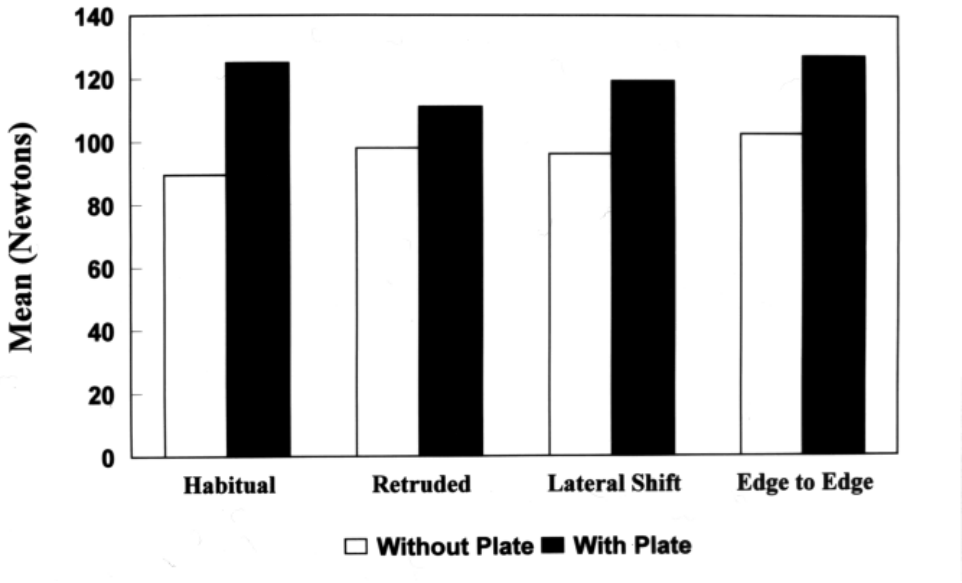

Figure 2
Mean peak resistance of neck flexors biting with and without bite-elevating plate in four mandibular positions.

Without a bite-elevating plate, only the mean of the edge-to-edge position was significantly greater than that of the habitual position. When the mandible was brought to the edge-to-edge position, the posterior teeth are disoccluded, increasing the vertical dimension. In retrusion, the teeth occlude along the posterior mesio-distal inclines which increases the vertical dimension, but not as greatly as in the edge-to-edge position. This may account for the significant (14%) increase in strength from the habitual bite to the edge-to-edge bite without a plate. In a lateral shift position, the intercuspal contacts ride up the palatal inclines of the upper buccal cusps, also raising the vertical dimension, but to a lesser degree than in the edge-to-edge position. The retruded and lateral shift positions without a plate, therefore, are at a higher vertical than the habitual position, but less than the edge-to-edge position. This could account for the tendency toward their intermediate strength level.

The habitual and edge-to-edge elevated positions produced an equivalent strength increase over habitual baseline (40% and 42% respectively). Both of these means were the highest obtained in the study and significantly greater ($p < 0.01$) than the mean of the retruded position but not of the lateral shift position.

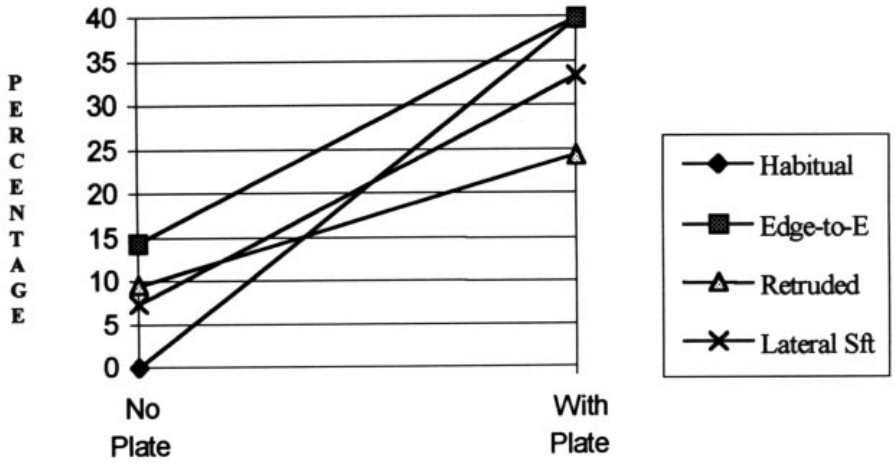

Figure 3
Mean percent cervical flexor strength increase above habitual bite, nonelevated baseline.

Table 4
Measured Increases of Vertical Dimension (mm) for 15 Subjects to Achieve Peak Isometric Cervical Flexor Strength in Habitual Bite

Subject number	Increase mm
1	3.8
2	2.4
3	1.5
4	1.5
5	2.7
6	3.0
7	2.6
8	2.1
9	3.4
10	2.6
11	1.9
12	2.6
13	2.6
14	1.6
15	1.7

Mean = 2.4 mm
Range 1.5-3.8 mm
Standard Deviation

This graded response (**Figure 2**) suggests that isometric strength may increase as the vertical dimension increases from habitual bite up to a maximum. An earlier study by Parker, et al.[18] failed to show this phenomenon with isokinetic strength but Tsukimura[28] found such a graded phenomenon with back muscles.

With one exception, increasing the vertical dimension increased the mean isometric strength of the cervical flexors significantly, regardless of mandibular position (**Table 3**). The exception was that the edge-to-edge position without a plate was no different from the retruded position with a plate. **Figure 3** shows that among the elevated positions, the smallest strength increase occurred in the retruded position (24% above habitual baseline) while without the plate, the largest increase from baseline occurred in the edge-to-edge position (14% above habitual baseline).

The demonstration of a significant increase in peak isometric strength with bite elevation implies that less demanding strength tasks (sub-maximal posturing) will also show an increase in strength with bite elevation. Should future research uncover this phenomenon at lower strength requirements, the role of cumulative stress from the prolonged isometric task of maintaining head posture with marginally weak muscles will be clarified. The present results support the emergent hypothesis that at a higher vertical dimension, the head posturing task of overclosed patients would not be as stressful for the muscles because of their increased length and strength. Clinical reports have shown[34-37] that in the masseter, as well as in the sternocleidomastoid muscles, tenderness to palpation diminishes after the use of occlusal splints which elevate the vertical dimension.

Present findings also suggest a possibility that future research may find that other head posturing muscles are strengthened with increased vertical dimension.

It is possible that forward head posture associated with reduced vertical dimension causes a chronic shortening of cervical flexors. At less than optimal functional length these muscles will not be as efficient, resulting in weakness and increased chronic tension levels. It has been shown that increased vertical dimension of the mandible at rest, joined with physical therapy procedures, can improve the posture of the head and neck.[31] Urbanowicz[38] pointed out research that suggests an increased vertical dimension may be associated with extension of the head on the neck. Daly, et al.[30] opened the bite of 30 male, asymptomatic dental students eight mm. Extension of the head occurred in 90% of the subjects. Watson and Trott[33] reported that forward head posture was associated with cervical headache, less isometric strength and less endurance of upper cervical flexors when compared with non-headache controls. Mandibular position appears to be inexorably associated with the head's position on the neck.

Leib[39] has proposed the interrelationship of the mandibular position to the cervical spine, head posture and balance. From his point of view, an improper mandibular relationship is associated with impaired posture and balance. At least one study has shown an improvement in equilibrium associated with increased vertical dimension.[29]

Conclusion

The results suggest that the function of some of the muscles that support the head are influenced by variations in the bite. The extent of the effect in those with deep bite can be as large as a 40% increase in maximum isometric strength over the level measured in habitual occlusion. These data suggest that the function of muscles which posture the head appears to be related to mandibular position and vertical dimension. Their interaction supports the concept of a craniomandibular-cervical masticatory system.

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