The Effect of Stepwise Increases in Vertical Dimension of Occlusion on Isometric Strength of Cervical Flexors and Deltoid Muscles in Nonsymptomatic Females

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0886-9634/2004-264$05.00/0, THE JOURNAL OF CRANIOMANDIBULAR PRACTICE,

Manuscript received July 23, 2001; revised manuscript received April 16, 2002; accepted April 17, 2002

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ABSTRACT: This mixed, single-double blind study examined the effect of a stepwise increase in vertical dimension of occlusion (VDO) on the isometric strength of cervical flexor and deltoid muscles in 20 asymptomatic females with deep bite (age range 20-40 years). Vertical dimension of occlusion was increased by mandibular acrylic bite plates, 2, 4, 6 and 12mm. Subjects were instructed to bite while resisting: 1. an increasing horizontal force was applied to the forehead; and 2. an increasing vertical downward force to the wrist of each extended arm. Forces were applied by a hand-held strain gauge until resistance yielded. The force applied at the point of yielding was recorded as isometric peak strength of that trial. The peak strength for each muscle group was measured twice and averaged to produce a mean peak strength measure. This procedure was repeated in the subject's habitual occlusion and for the four increased VDOs. Mean strength of cervical flexors with increased VDO (12.0 kg) was significantly greater than that for existing vertical dimension occlusion (9.6 kg). With the exception of pre-experimental existing VD of occlusion, strength for right and left deltoids did not differ, but mean deltoid strength in the increased condition (8.6 kg) was significantly greater than biting in without a bite plate (6.6 kg). In the peak condition, cervical flexor strength increased 24% and deltoid strength increased an average of 29% from that of biting without an increase. As VDO increased further, strength in all sites was found to diminish. Repeating the strength test without a bite plate, after all trials were administered, did not show differences from pre-experimental levels, indicating that fatigue was not an important factor. The findings demonstrate that isometric strength of the cervical flexors and deltoids increases significantly from habitual occlusion as the VDO is increased, then diminishes as VDO is increased further. The strength of both cervical flexors and deltoids varied in concert with changes of VDO.

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The relationship between mandibular position, vertical dimension of occlusion (VDO), and function of the masticatory system has been a topic of interest in dentistry for many years.[1-16] Active interest in this area accompanied by lack of thorough knowledge has spawned numerous concepts, theories, and treatment methods.

One of these concepts outlines the relationship between mandibular position and its effect on the isometric strength of the muscles of the extremities, the neck, or the back.[1,7,12,16-27]

Another recent concept defines the relationship between mandibular position and its effect on head and neck posture.[28-33] Other studies have focused on the role of VDO in TMD treatment as well as assessing the influence of VDO in the reduction of myofascial pain disorder (MPD) symptoms.[11,14,34,35]

The history of the relationship between mandibular position and the isometric strength of muscles started with clinical observations. May,[36] Stoll,[35] and Fonder[37] all observed, "that patients with proper occlusions had a greater endurance and a better performance than those with malocclusions." In the 1970s, Stenger[38] reported that, "the condition of the muscles of the jaw and the occlusion of the teeth could affect a player's performance." Some football players had a total lack of molar support. After providing molar support and establishing a physiologic relationship of teeth, normalization occurred rapidly.

Smith[39] was the first to investigate Stenger's proposed relationship. He conducted his study on 25 professional football players with a variety of temporomandibular joint dysfunction, stomatognathic muscle and bite abnormalities. He measured the muscle strength with the Cybex II Dynamometer, as well as by the kinesiologic deltoid pressure method. Applied kinesiologists[40,41] have long advocated this method of testing strength. The mandibular positions were compared with teeth together (acquired centric), wax bite position determined by kinesiologic testing and biting on an unadjusted bite guard. Although the Cybex measurements were not significant among positions, the kinesiologic testing *was* significant. He concluded that there was a relationship between the jaw, posture, and the ability of the arm muscles to contract strongly. The publication of Smith's clinical report was followed by a series of experimental and clinical studies[12,19-27,39,42-49] and reviews or commentaries.[50,51] Attempts were made to determine whether an increase in the VDO would cause a positive effect on muscle strength.

In Smith's second experiment,[23] strength was tested by the kinesiometer in three mandibular positions: 1. acquired centric occlusion; 2. an unadjusted mouth guard; and 3. a mandibular orthopedic repositioning appliance (MORA) set by the kinesiologic method. He noted that players with the deepest overbite and most significant vertical dimension loss, showed the greatest muscle testing improvement from using a mouth guard. Both of Smith's studies were criticized later for not including a statistical analysis of the data. Forgione, et al.[6] calculated nonparametric statistics on Smith's published data and found that the strength obtained with the MORA was greater than that with either the acquired centric bite or the unadjusted mouth guard. They also reviewed all the experimental and clinical studies that followed Stenger's clinical report. They concluded that: 1. most of the experiments used subjects with no apparent malocclusion or lack of posterior support; 2. an elevated vertical dimension of occlusion was set by diverse methods, assuming all bite elevating appliances to be equivalent; 3. data gathered from isokinetic strength tests were used to criticize findings of isometric strength tests (*strength* was ill-defined); and 4. placebo effect was used to explain findings of increased isometric strength by some authors, even though these authors did not find this phenomenon in their own studies nor has the placebo effect ever been found to be significant in any of the published studies. They also argued that studies could not be compared directly unless the same independent variable (design of the appliance to correct the particular condition set to an equivalent criterion) and the same dependent variable (measure of isometric strength) are used.

Williams[26] also reported a similar finding where the strength of arm adductor and abductor muscles of 23 athletes increased with a splint that supported the rest position.

Abduljabbar,et al.[1] in a double-blind study tested the isometric strength of the extremities and shoulder girdle on female temporomandibular dysfunction (TMD) patients with deep overbites. Isometric strength using a bite-elevated intraoral splint increased significantly from habitual occlusion and placebo splints. This study demonstrated a functional relationship between maxillomandibular changes and variations in isometric strength throughout the body.

Abdallah, et al.[17] conducted a double blind study to determine the effect of vertical dimension of occlusion and mandibular posture on isometric strength of the deltoid muscles in deep bite subjects. Using a strain gauge for muscle testing, each subject was tested in four conditions: 1. habitual occlusion; 2. teeth apart; 3. with a bite-elevating appliance; 4. with a placebo appliance. They found that increasing the VDO by using a bite-elevating appliance significantly increased the isometric resistance of the deltoid muscles above the level obtained with habitual occlusion and placebo. The mean difference between IDP resistance in habitual occlusion versus the placebo appliance was not statistically significant.

Al-Abbasi, et al.[18] investigated the relationship between VDO and the isometric strength of the cervical flexors. The results showed that increased vertical dimension with the bite plate set to a functional criterion significantly increased the isometric strength of the cervical flexor muscles.

Aboushala, et al.[16] assessed the isometric strength of cervical flexor muscles in 16 complete denture patients at different vertical heights: without the denture, with the denture, rest position, two mm, six mm, and ten mm increased VDO above denture height. They concluded that altering the VDO appears to have a significant effect on the isometric strength of the cervical flexor muscles in complete denture patients. Of interest was the finding that increasing VDO beyond a peak height actually decreased isometric strength.

Tsukimura[29] tested the back strength of eight subjects at different vertical dimensions of occlusion. Back strength was the weakest in the disoccluded mandibular positions, but tended to increase at two, five, and ten mm of splint thickness and decrease when a 15 mm thickness appliance was worn. Drago, et al.[52] applied maxillary splints of varying thicknesses to evaluate whether excessive vertical dimension caused muscular hyperactivity. Interestingly, the thickest splints had the greatest decrease in muscle activity.

Several studies have discussed muscular adaptation to the increase of vertical dimension caused by splint insertion.[4,34]

Forgione, et al.[6] in a critical review pointed out that bite plates of different design may have different effects on both isometric and isokinetic strength. For example, using eleven subjects McArdle, et al.[45] fashioned a splint in accord with transcutaneous electrical neurostimulation to determine a "myocentric bite position." No difference from placebo was found in hand grip, elbow flexion, and leg extension. Although this result appears to contradict the findings of increased isometric strength, it has yet to be shown that a bite plate fashioned in this manner is equivalent in its effects on strength measured while biting on a bite plate fashioned in accord with a functional criterion (peak deltoid strength).

The objective of this study was to determine the effect of stepwise increases in VDO on the isometric strength of both cervical flexors and deltoid muscles in asymptomatic females with deep bite.

Materials and Methods

Twenty female subjects (age 20-40 years) were selected from the staff, faculty and students at Tufts University School of Dental Medicine.

The inclusion criteria were: 1. subjects must have had a full physical examination within the last twelve months; and 2. complete dentition or at least 28 teeth.

Subjects who had the following were not accepted into the study: 1. medical systemic problems that could affect muscular function, such as, myalgia, myositis and fibromyalgia; 2. history of severe head and neck trauma (fractures or whiplash injury) in past one year; 3. major abnormalities of postural alignment; 4. TMJ symptoms such as joint pain on palpation, joint noise, or major deviations in mandibular movement; 5. occlusal abnormalities affecting normal jaw closure; and 6. the presence of five or more permanent dental restorations (i.e., crowns, bridges, implants and or removable prostheses).

Males were excluded from participation in this study to ensure a homogeneous population and to narrow extreme variations in strength.

Only subjects with a measurable overbite of greater than 10% were included in the study. The overbite was measured by obtaining the length of a full mandibular incisor crown by a paper ruler extended from the highest point of the incisal margin to the lowest point of the labial gingival margin. The overbite was obtained by marking on the paper ruler and counting how much of the mandibular incisor was hidden by the upper incisor. These recordings were expressed as percent overbite. **Table 1** shows the distribution of subjects with overbite at different percentages of overbite.

Impressions were taken for upper and lower dental arches and bite registration was made. Using a face-bow, models were mounted on a Whip Mix (Whip Mix Corp. P.O. Box 17183, Louisville, KY USA) articulator. By adjusting the articulator's vertical stop, full arch acrylic lower occlusal bite plates were fabricated in maximum intercuspation at four different vertical levels (two, four, six and twelve mm). The four bite plates for each subject were numbered and kept in a box. Before the experiment began, the bite plates were adjusted in the mouth to ensure that maximum intercuspation was achieved.

During the second visit the isometric strength of the cervical flexors (CF) and left and right deltoid muscles was measured by a strain gauge in pre-experi-

Table 1
The Distribution of Percentage of Overbite and Number of Subjects At Each Value

Overbite %	Number of subjects
10	1
11	2
15	1
27	1
33	2
37	2
44	1
50	4
53	1
58	1
62	2
71	1
89	1
Total	20

mental occlusion, four different bite elevations and post-experimental occlusion without bite plate. A five-minute rest was given between each test and 15 minutes between the cervical and deltoid tests.

Isometric Strength Testing for Cervical Muscles

The subject was seated on a dental chair in a comfortable upright position. The subject's head was in a neutral postural position. The subject's eyes were looking straightforward at a fixed point on the front wall. The headrest of the chair was adjusted so that there was a one-inch space between it and the subject's head to prevent overextension of the neck. The subject's shoulders were stabilized during the test. The subject was instructed to resist to the limit of her ability the pressure applied to the forehead by the strain gauge (**Figure 1**).

Isometric Strength Testing for the Deltoid Muscle

The subject was seated on a dental chair in the same positioning as related above during the cervical muscle test. The test was performed sequentially on the two arms. The subject's arms were extended to the side at the same level of the shoulder and parallel to the floor. Downward pressure was applied to the extended wrist with the strain gauge while stabilizing the contra lateral shoulder to prevent tipping of the body (**Figure 2**).

Figure 2
Testing for deltoid isometric peak strength using a strain gauge (IPS).

Blinding Procedures

Measurements of isometric strength of the cervical muscles and right and left deltoids were collected at six points in time: pre-experimental occlusion without bite plate, four different bite elevations, and post-experimental occlusion without bite plate. This constituted a mixed single-double-blind design. Measurements obtained pre- and post-experimentally were single blinded, because it was obvious to the experimenter that there was no bite plate inserted. Measurements taken with the bite plate inserted were recorded under double-blinded conditions, because the experimenter could not see which of the four bite plates was inserted.

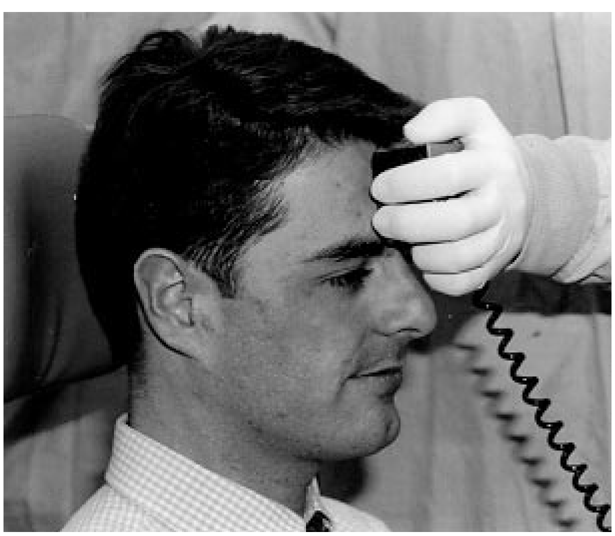

Figure 1
Testing for cervical flexors isometric peak strength using a strain gauge (IPS).

The first examiner made sure that the subject's seated position was appropriate. Then, he assigned the subject to one of the randomization groups. The bite plate was inserted by the first experimenter and then he left. The second examiner entered the room and performed the muscle testing. At no time was the subject informed on which plate she was biting. All data were recorded on a strip chart recorder.

Data

Subjects were instructed to resist to their maximum ability, while biting. An increasing horizontal force was applied to the forehead and an increasing vertical downward force to the wrist of each extended arm. Forces were applied by a hand-held strain gauge until resistance yielded. The force registered at the point of yielding was recorded as peak isometric strength of that trial. This peak strength for each muscle group was measured twice and averaged to produce a mean peak strength measure. This procedure was repeated in the subject's habitual occlusion pre- and post-experimentally and for the four increased VDOs.

Results

A two-way ANOVA of cervical flexor mean peak strength showed a significant main effect ($F_{df=4}$ =12.3, p<0.00001). **Table 2** shows that the isometric cervical peak strength was no different pre- and post-experimentally indicating that no fatigue had occurred during the testing. The mean of the maximum strength trial was significantly greater than both the pre- and post-experimental levels. Mean strength of the cervical flexors with elevated bite (12 kg) was significantly greater than that for habitual occlusion both pre-experimentally (9.6 kg) and post-experimentally (9.4 kg). The means of the pre-maximum and the post-maximum trials were also significantly less than the mean maximum strength trial.

A two-way ANOVA performed on the isometric strength of the right and left deltoid muscle data showed a significant main effect ($F_{df=9}$ = 20.20, p<0.00001) (**Table 3**).

With the exception of the pre-experimental habitual occlusion trial, strength for right and left deltoids did not differ in all conditions. Although there was a significant difference between the right and left mean isometric deltoid strength pre-experimentally (6.9 kg, right; 6.4 kg, left), this difference was small (0.5 kg). Because of this significant difference, **Figure 3** shows values of percent difference from the pre-experimental baseline.

Mean maximum deltoid strength in the elevated conditions (8.6 kg, right; 8.6 kg, left) were significantly greater than biting in habitual occlusion pre- (6.9 kg, right; 6.4 kg, left) and post-experimentally (6.5 kg, right; 6.3 kg, left).

The pre-maximum trial means were no different from the respective post-maximum values but both were significantly less than their respective maximum strength

Table 2
Two-way ANOVA of Isometric Strength (kg) for Cervical Flexors (Pre- and Post-Experimental Occlusion, Pre- and Post-Maximum Increased Bite Strength and Maximum Increased Bite Strength) and Paired Comparison of All Possible Combinations of Means (n=20)

Source	DF	Sum of squares	Mean square	F-ratio	p-level
A	4	89.4	22.3	12.3	<0.00001
S	19	655.4	34.5		
Error/AS	76	138.1	1.8		
Total	99	882.9			

Mean and Standard Deviation of Each Experimental Condition

	Mean kg (± Standard deviation)
Pre-Experimental	9.6 (±3.17)
Pre-Maximum trial	10.8 (±3.11)
Maximum strength	12.0 (±3.12)
Post-Maximum trial	9.9 (±2.76)
Post-Experimental	9.4 (±2.13)

Comparison of All Possible Pairs of Means

	Pre-Expt. trial	Pre-Max. trial	Max. strength	Post-Max. trial	Post-Expt. trial
Pre-Expt. trial	-	<0.01	<0.001	NS	NS
Pre-Max. trial		-	<0.01	NS	<0.01
Max. strength			-	<0.001	<0.001
Post-Max. trial				-	NS
Post-Expt. trial					-

Expt. = Experimental; Max. = Maximum; NS=Not significant.

Table 3

Two-way ANOVA of Isometric Strength (kg) for the Right and Left Deltoid (Pre- and Post-Experimental Occlusion, Pre- and Post-Maximum Increased Bite Strength and Maximum Increased Bite Strength) and Paired Comparison of All Possible Combinations of Means (n=20)

Source	DF	Sum of squares	Mean square	F-ratio	p-level
A	9	121.6	13.5	20.2	<0.00001
S	19	249.28	13.1		
Error/AS	171	114.35	0.67		
Total	199	485.23			

Simple index of skew/trial eight only>20%: 22.07%, Bartlett's test for equality of variance: Chi Square 2.05, df=9, p>0.10

Mean and Standard Deviation of Each Experimental Condition

	Mean of right deltoit (kg) (± Standard deviation)	Mean of left deltoid (kg) (± Standard deviation)
Pre-Experimental	6.9 (±1.6)	6.4 (±1.4)
Pre-Maximum trial	7.4 (±1.3)	7.3 (±1.3)
Maximum strength	8.6 (±1.3)	8.6 (±1.4)
Post-Maximum trial	7.5 (±1.4)	7.2 (±1.6)
Post-Experimental	6.5 (±1.4)	6.3 (±1.2)

Comparison of All Possible Pairs of Means

	Rt delt Pre-Ex	Rt delt Pre-Max	Rt delt Max	Rt delt Post-Max	Rt delt Post-Ex	Lt delt Pre-Ex	Lt delt Pre-Max	Lt delt Max	Lt delt Post-Max	Lt delt Post-Ex
Rt delt pre-ex	-	NS	<0.001	<0.05 >0.02	NS	<0.05 >0.02	NS	<0.001	NS	<0.02
Rt delt pre-max		-	<0.001	NS	<0.001	<0.001	NS	<0.001	NS	<0.001
Rt delt max			-	<0.001	<0.001	<0.001	<0.001	NS	<0.001	<0.001
Rt delt post-max				-	<0.001	<0.001	NS	<0.001	NS	<0.001
Rt delt post-ex					-	NS	<0.01	<0.001	<0.01	NS
Lt delt pre-ex						-	<0.001	<0.001	<0.001	NS
Lt delt pre-max							-	<0.001	NS	<0.001
Lt delt max								-	<0.001	<0.001
Lt delt post-max									-	<0.001

Rt=Right; Lt=Left; Delt=deltoid; Ex=Experimental; Max=Maximum strength; NS=Not significant

trial means. The right and left mean isometric deltoid strength pre- and post-experimental were not significantly different, indicating that fatigue was not a factor. In addition, it is interesting to note that performance of right and left deltoids did not differ significantly over all trials, indicating that handedness was not an issue.

Using the habitual pre-experimental bite strength as baseline, the mean maximum isometric strength was calculated as percent difference from baseline. In the peak condition, cervical flexor strength increased 24% and deltoid strength increased an average of 29% from that of habitual occlusion.

Figure 4 summarizes the pre- and post-experimental mean strength values for the three muscle groups tested. It can be observed that the difference for each muscle group, pre- and post-, is negligible. Also, in each muscle group there was a significant increase in the peak strength trials.

Figure 3 shows the mean percent difference from pre-experimental baseline (habitual occlusion) of isometric strength at pre-maximum trial, maximum strength trial, post-maximum trial, and post-experimental habitual occlusion trial. It can be observed that as the vertical dimension is increased from habitual occlusion, strength tends to increase to a distinctive peak at the maximum strength trial followed by a reduction in strength as the bite is opened further.

To determine whether the maximum isometric strength of the three muscle groups tended to occur at the same bite elevation for each subject, a Pearson product moment correlation was performed (**Table 4**).

The maximum cervical flexor strength and maximum

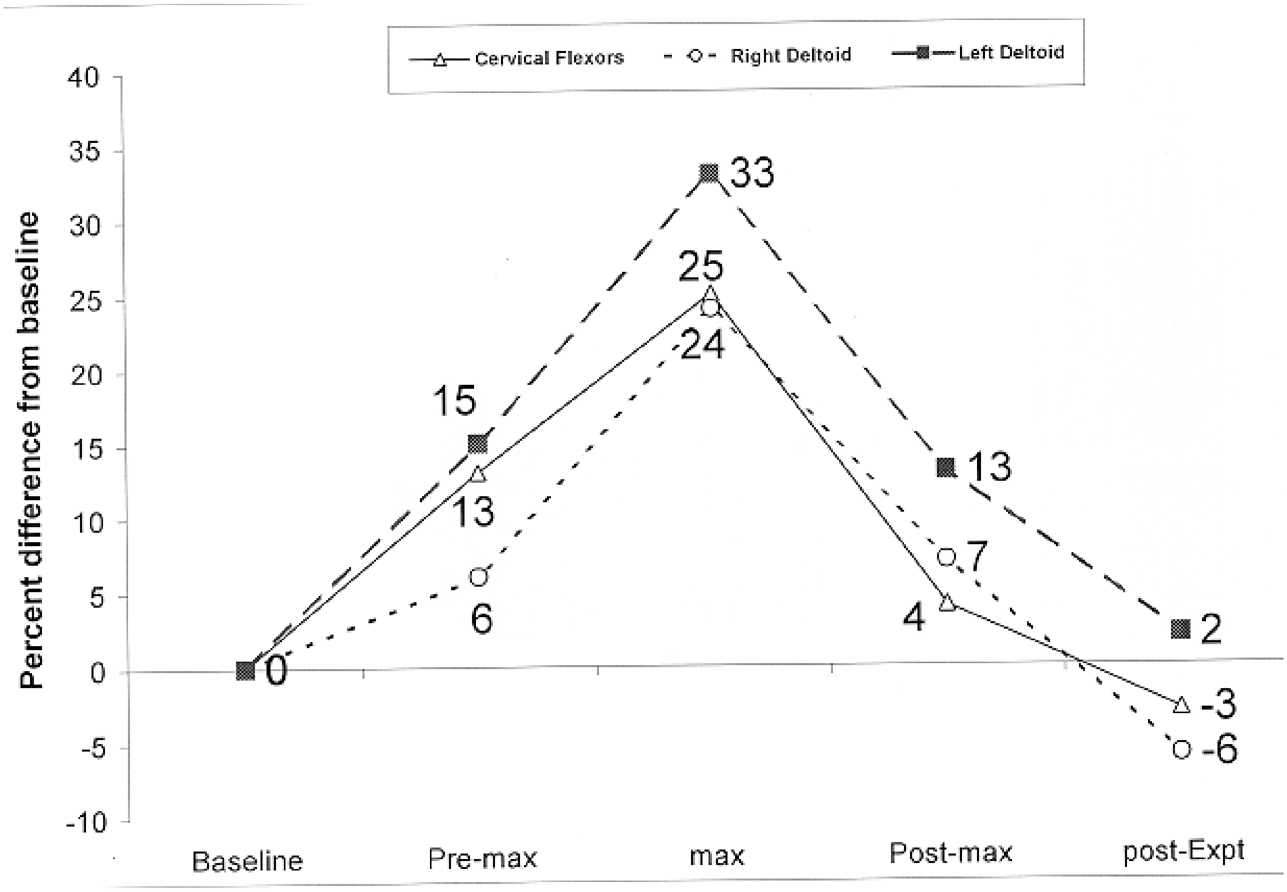

Figure 3
Mean percent difference of cervical flexors, right and left deltoids from baseline (pre-experimental occlusion, pre-maximum, maximum, post-maximum and post-experimental strengths).

right and left deltoid strengths were highly correlated with the number of millimeters elevated on these trials. The maximum strength of all three muscle groups occurred at the same bite elevation in 13 subjects. Six of the remaining seven subjects showed maximum strength in two of the three muscle groups at the same bite elevation and only one subject exhibited maximum strength of the three muscle groups at three different bite elevations.

Discussion

Forgione, et al.[6] pointed out the distinction between isometric and isokinetic strength. In testing isometric strength, muscle length remains constant while applied force is either constant or variable. In measuring isometric strength, one measures postural strength. Measuring isokinetic strength measures the strength of muscles in movement. In accord with previous studies,[1,6,7,16,18] isometric strength was found to increase significantly with elevation of the vertical dimension. These studies used the deltoid isometric press, a functional test to set the vertical dimension at the peak of deltoid strength. The current study used arbitrary steps of increase to determine objectively the isometric strength peak. The findings indicate that there is a vertical dimension which produces a peak increase in isometric strength for both cervical flexors and deltoids.

Clinical observation[6,22] contended that in the case of lack of posterior support or lack of appropriate vertical dimension, elevation of the vertical dimension resulted in a graded increase in isometric strength up to a maximum. With further elevation a decrease in isometric strength occurred from that maximum. The graphical representation of this phenomenon resembled an *inverted* "U" or a bell shaped curve.

Hart, et al.[43] tested this phenomenon with elbow flexor isokinetic strength as the dependent variable while increasing the vertical dimension of occlusion one, three,

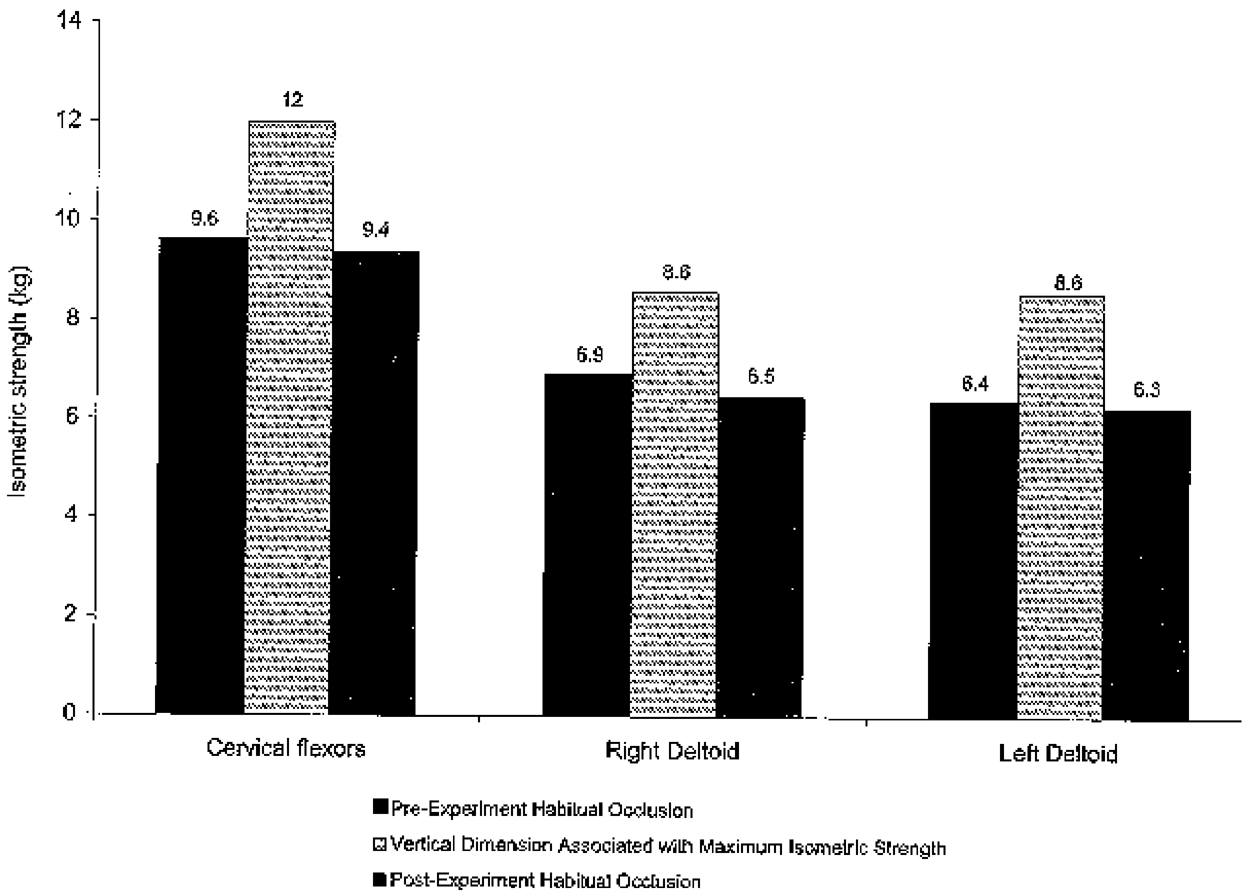

Figure 4
Comparison between isometric strength of the three muscle groups in pre- and post-experimental nonelevated occlusion and vertical dimension associated with maximum isometric strength.

five, and seven mm above habitual bite. They did not find such a relationship. However Forgione, et al.[6] argued that increase in VDO affected isometric strength to a far greater degree more than isokinetic, if it affects isokinetic strength at all.

Table 4
Pearson Product Moment Correlation of All Pairs of Muscle Groups At the Bite Elevation Yielding Maximum Strength (n=20)

	Cervical flexors	Right deltoids	Left deltoids
Cervical flexors	1.00		
Right deltoids	0.87*	1.00	
Left deltoids	0.89*	0.78*	1.00

*p=0.01

However, Tsukimura[29] used isometric strength as the dependent variable and found that back strength increased as two, five, and ten mm splints were worn and tended to decrease when a 15 mm appliance was worn. The present study, similar to that of Tsakimura,[29] recorded changes in isometric strength at two, four, six, and twelve mm elevations above habitual bite. It was found that increasing VDO in this fashion produced an increase in isometric strength up to a peak. With further increase in VDO strength tended to decrease. This finding (**Figure 3**) is in accordance with the findings of Tsakimura.[29]

Since the baseline strength of the deltoids pre-experimentally differed, right from left, variability in strength was measured in terms of percent difference from the habitual bite baseline of each subject. **Figure 3** shows what was revealed by the analyses of variance, that pre-maximum and post-maximum trials were weaker (vertical dimension lower and higher than vertical dimension of the maximum strength trial). In addition, the strength associated with both of these vertical dimensions was greater than pre-experimental and post-experimental habitual bites (the vertical dimension of the nonelevated bite). The appearance of the graphical representation resembled an *inverted* "U" or a bell shaped curve.

An interesting finding of this experiment, which has not heretofore been demonstrated, is that both deltoid muscles and cervical flexors tended to achieve maximum strength at the same vertical dimension. Thirteen of twenty subjects achieved maximum strength in the three muscle groups at the same vertical dimension elevation while six achieved maximum strength of two muscle groups at the same elevation and only one subject showed maximum strength of the three muscle groups at three different vertical dimensions. The correlation of the vertical dimension value producing maximum muscle strength between right and left deltoids was 0.78 (P<0.01), between cervical flexors and right deltoids 0.87 (P<0.01) and between cervical flexors and left deltoids 0.89 (P<0.01). This finding suggests that strength increase occurs similarly in different muscle groups when the bite is elevated. In other words, a given vertical dimension increase does not affect only one muscle group and not another. This finding supports the practice of obtaining the vertical dimension by the functional criterion of peak deltoid or cervical flexor isometric strength.[1,6,16,18]

The degree of isometric strength increase found in this study is similar to other studies of bite and isometric strength. Al-Abbasi, et al.[18] measuring isometric strength of the cervical flexors found a range of 24-42% increase above habitual occlusion strength. Abduljabbar, et al.[1] measuring strength in various body sites (elbow, shoulder, knee, extension, and flexion) found a range of 12.5-21.5% increase with an elevated bite determined functionally, i.e., the isometric deltoid press. Aboushala, et al.[16] measuring the cervical flexor strength while biting on dentures found an increase of 30% above habitual occlusion strength. When they measured cervical muscle strength while biting without dentures they found a 90% increase with the elevated bite. The range in the three muscle groups studied in the current experiment was 24-33% above baseline habitual bite. The findings of this study support the need for the dentist to understand the complete interrelationship existing between maxillo-mandibular relationships and the postural muscles of the cervical spine and shoulder girdle.

A vicious circle with clinical implications is suggested by this study's findings. Improper vertical dimension (malpositioned mandible) affects the postural strength of muscles not regarded as part of the stomatognathic system. These muscles in turn affect mandibular position which in turn could affect the postural muscles of the body.

At this point in time, experimental efforts are directed toward establishing the functional relationship between vertical dimension and isometric strength. Hopefully, as the data increase, the physiological mechanism underlying this phenomenon will become clear.

Conclusions

Increasing vertical dimension of occlusion is monotonically related to increase in isometric strength of the deltoids and cervical flexors. Increase of the vertical dimension beyond the height associated with maximum strength results in a decrease of isometric deltoid and cervical strength. Therefore, there is a vertical dimension unique to each subject, which maximizes isometric strength. The current data suggest that other muscle groups may attain maximum isometric strength at the same or similar vertical dimension.

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