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Effect of different advancement positions on the maximum retrusive force of the mandible

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Structured Abstract

Introduction – Functional appliances lead, in different degrees, to loss of anchorage in the lower arch. By anchoring them to the mandibular bone, any dental side effects may be avoided and the skeletal effect enhanced. Stability of bone-borne fixation would be affected by forces created by the pull of the masticatory muscles. We aimed to identify mean maximum forces produced by mandibular retrusive muscles, at different degrees of advancement.

Subjects and methods – Eighteen healthy adult volunteers participated in the study. Maximum retrusive force was measured using a splint/load cell system. Readings of the maximum forces of retrusion were taken from five mandibular positions: unstrained retruded position, and 4, 5, 6, and 7 mm anterior to the unstrained position. Data were presented as means \pm SD and ANOVA was performed to examine statistical significant differences between means of the maximum retrusion force.

Results – Mean maximum retrusion force ranged between 63.3 and 198.2 newtons at the unstrained and 7 mm positions, respectively. It increased as the distance of advancement increased, being statistically significantly ($p < 0.05$) less at unstrained position compared with all advancement distances, 4 mm of advancement than 6 and 7 mm advancement, 5 mm of advancement than at 7 mm advancement.

Conclusion – Magnitude of the forces exerted by muscles during voluntary maximum retrusion movement from different advancement positions increased proportionately as the retrusion distance increased up to 7 mm. Such range of high forces might be important to consider when designing a bone-borne functional appliance.

Key words: mandibular advancement; muscle strength; orthodontic appliances, functional; orthodontics; retrusion force

Introduction

The correction of a class II division 1 malocclusion by means of functional appliances is a frequent treatment approach (1). Numerous studies have focused on the mode of action of the different types of removable functional appliances, evaluating their dental and skeletal effects. Several studies reported the effectiveness of fixed functional appliance for correction of class II malocclusion in adult human subjects (2–6) and experimental animals (7, 8) and found a correction of 78% dental and 22% skeletal (5). None of the available removable or fixed teeth-borne functional appliances could fully address the problem of anchorage loss in the mandible and the subsequent proclination of the lower anterior teeth (9, 10). Passive stabilization of teeth-supported fixed functional appliances has been advocated through attachment of these appliances to mini-screws and therefore aids in avoiding the anchorage loss on the lower incisors (11).

The use of temporary anchorage devices such as mini- and osteosynthesis screws in the field of orthodontics offers new horizons by fixing functional appliances directly to the mandibular alveolar bone in the region of the mental foramen (Fig. 1) to correct mild skeletal class II malocclusion. Such appliance would have the advantage of increasing the skeletal component by avoiding the proclination of the lower incisors or forward pulling of the whole lower dentition that occurs with any teeth-borne removable or fixed functional appliance, thus improving esthetics and decreasing the need for surgery or camouflage therapy.

In general, cemented fixed functional appliances, such as the Herbst appliance, are subjected to very high muscular force (12), for example, during functional activities: eating, talking, or by strong backward retrusion of the mandible that may be purposely done by patients voluntarily during daytime or unconsciously at night. These acting forces may lead to failure of the appliance and detachment from teeth or breakage (13). A major consideration for a possible mandibular bone-borne functional appliance is its stability

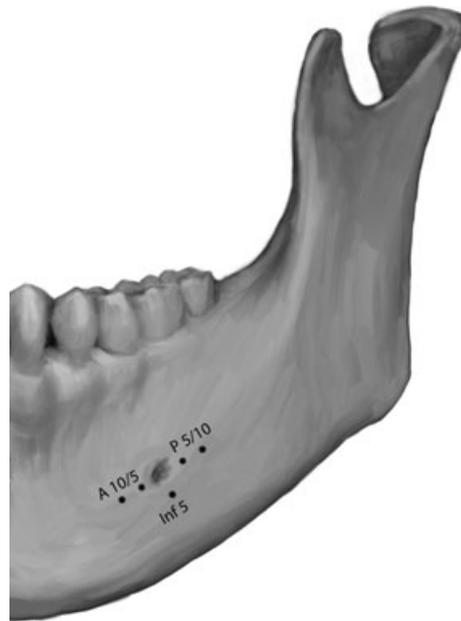


Fig. 1. Locations around the mental foramen whose bone thickness was measured: 5 mm (A5) and 10 mm (A10) anterior; 5 mm (P5) and 10 mm (P10) posterior; and 5 mm (Inf5) to the mental foramen (Courtesy of Roger Zwahlen and Werner Käser, University of Zurich, Zurich, Switzerland).

under such forces in the oral cavity. Many studies have dealt with maximum biting effort (14–17), while few have dealt with the magnitude of forces produced on maximal mandibular exertion in a sagittal direction (18, 19) or mandibular retrusive movement (20, 21). Some studies have reported the maximum forces exerted on retrusion of the mandible (18, 22). However, none appears to have attempted to measure the maximum voluntary force generated during retrusion in adults from different advancement positions.

The aim of this study was to identify mean forces produced by mandibular retrusive muscles, as measured on self-assessed maximum voluntary contraction in adult healthy subjects to a tension/compression load cell system, at different degrees of advancement.

Material and methods

The study protocol had been approved by the Ethical Committee (IRB ref. UW06-175 T/1200), The University of Hong Kong, SAR, China. Informed consent was obtained from all participants.

Subjects

Eighteen healthy subjects (10 men and eight women) volunteered to participate in this study. All subjects were postgraduate dental students at the University of Hong Kong, SAR, China (mean age 30.5 ± 3.6 years) and had no history or symptoms of pain and/or functional disturbances in the temporomandibular joints and/or masticatory muscles. All subjects had a minimum of 28 teeth. Prior to measurement, the purpose and procedure of the study were explained in detail.

Records

Upper and lower impressions and face bow registration were taken for each subject. To facilitate mounting the plaster casts on a semi-adjustable articulator (Dentatus ARL; AB Dentatus, Hagersten, Sweden), interocclusal wax bite records were taken at centric occlusion and at edge-to-edge incisor relationship.

Measurement device

A simple measurement device was developed to measure the forces exerted during maximal efforts to retract the mandible. This device consists of upper and lower heat cured acrylic splints, individually fabricated for each subject on the mounted plaster casts, with minimal thickness of acrylic occlusally while having sufficient strength to withstand the retrusion forces. An acrylic rod was attached to the upper splint, and a stainless steel button with a hook was attached to the lower splint (Fig. 2).

Maximum retrusive force was measured using a tension/compression load cell system (Model 31; RDP Electronics Ltd, Wolverhampton, UK), which could measure forces up to 446 newtons (N). The load cell and a transducer indicator (E725 microprocessor based digital indicator/panel meter; DP Electronics Ltd) were connected to a computer for data recording. The load cell was attached to the rod (on the upper splint) through a vertical stainless steel plate and a 5-mm-diameter stainless screw. A detachable cylinder with a hook was attached to the load cell to allow a two-

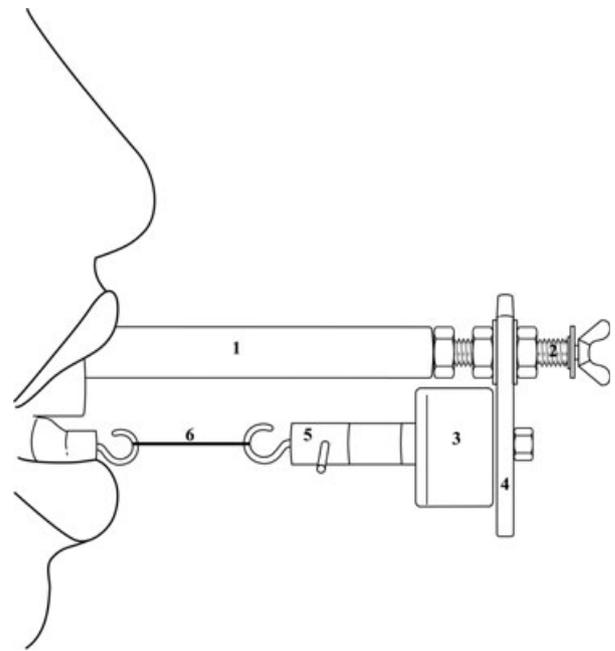


Fig. 2. Illustration of the measuring device: 1) Acrylic rod; 2) 5-mm-diameter screw; 3) Load cell; 4) Stainless plate; 5) Detachable cylinder; and 6) Thread.

layer braided line (thread) [YGK JIGMAN (Dyneema) $\times 8$ 80 lb-300m IGFA class P.E line, YGK, Japan], to easily connect the load cell to the hook on the lower splint (Fig. 2). The thread had a securely tied knot at each end and was pre-stretched to avoid any slippage in the tied knots and change in the length during measurement.

Recording procedure

Each subject was seated in an upright relaxed position in an unsupported natural head posture. Light body rubber base material (3M™ ESPE™ Imprint™ Bite Registration) was applied inside the upper and lower splints, which were then placed in the mouth and held steady until the material had set.

Readings were taken of the maximum forces of retrusion from five mandibular positions: unstrained retruded position (P0), and the following protrusive positions: 4 mm (P4), 5 mm (P5), 6 mm (P6), and 7 mm (P7) anterior to P0.

For P0, the length of the thread was predetermined with the splints on the articulator in centric position. For retrusion from protrusive position, the distance between the load cell and the hook on the lower splint was adjusted to place the

lower anteriors 4, 5, 6, and 7 mm anterior to P0 in the sagittal plane. Then, the subject was asked to advance the mandible until the thread (extending from the hook on the mandibular splint) could be attached to the hook on the load cell.

The testing procedures were explained to the subjects, and they were asked to start maximal (abrupt) retrusion of the mandible and then stop retrusion once their maximum retrusion capability was achieved. After each retrusion, subjects were asked whether they felt having made a maximal effort. If not, the result was discarded and the retrusion repeated. Between each assessment, subjects were given a resting period of at least 2–3 min.

The maximum force was recorded at the peak values of the readings for all five mandibular positions. Each subject performed five trials for each position, and the amplifying unit was reset to zero before each measurement. All tests were carried out by one person (A. A.) using identical testing procedures.

Statistical analysis

Data analysis was carried out using the SPSS version 13.0 for Windows (SPSS, Chicago, IL, USA). Data were presented as means \pm SD. For each subject, five repeated measurements were made for each step, and the one subject measurement reproducibility was investigated using coefficient of variance for duplicate measures. The first three trials had the lowest coefficient of variance and were therefore used for statistical analysis.

To examine statistical significant differences between means of the maximum retrusion force exerted at different positions, one-way analysis of variance (ANOVA) was performed at 95% level of confidence corrected with Bonferroni's post hoc test for multiple comparisons (Table 1). The level of significance was set at $\alpha = 0.05$.

Method error

The maximum retrusive force was performed twice for five subjects with 4 weeks apart, and values were compared using Dahlberg's formula $\pm\sqrt{\sum d^2/2n}$ (23), where d is the difference between the two registrations of a pair and n is the number of double registrations. A paired t -test was performed to compare the repeated measurements. Analysis indicated no significant difference in repeated measurement.

Results

The mean retrusion force and standard deviation at P0 and in the more anterior located points of measurement are depicted in Table 1 and Fig. 3. At P0, the voluntary retrusion force yielded mean values 63.3 ± 18.3 N. There was a progressive increase in the mean maximum retrusive force with increasing distance of protrusion. In more sagittally advanced mandibular positions, the mean retrusion force increased steadily reaching force values of 132.9 ± 38.9 N at 4 mm, 153 ± 42.7 N at 5 mm, 175.8 ± 47.9 N at 6 mm,

Table 1. Descriptive statistics for the maximum retrusive force in newtons

Advancement of the mandible (mm)	n	Mean	Std. deviation	Std. error	95% Confidence interval for mean			
					Lower bound	Upper bound	Minimum	Maximum
0	18	63.31	18.31	4.32	54.20	72.41	36.00	99.23
4	18	132.85	38.92	9.17	113.50	152.21	58.07	189.93
5	18	152.98	42.72	10.07	131.73	174.22	86.17	241.60
6	18	175.78	47.85	11.28	151.98	199.57	98.50	268.37
7	18	198.18	53.72	12.66	171.47	224.89	115.07	280.00

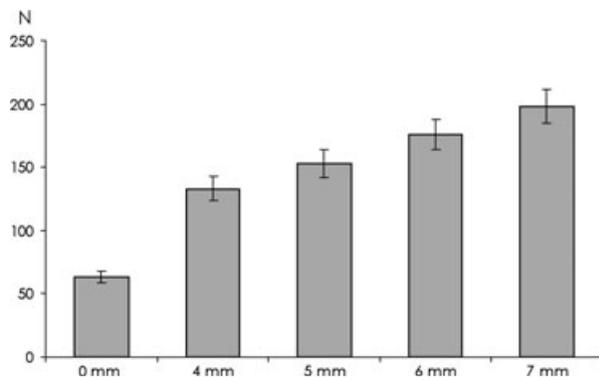


Fig. 3. Mean values for the maximum retrusion forces from different advancement positions. The mean maximal retrusion force increased as the retrusion distance increases. Y axis shows the force in N and the X axis shows the distance in millimeter. Error bars show SD.

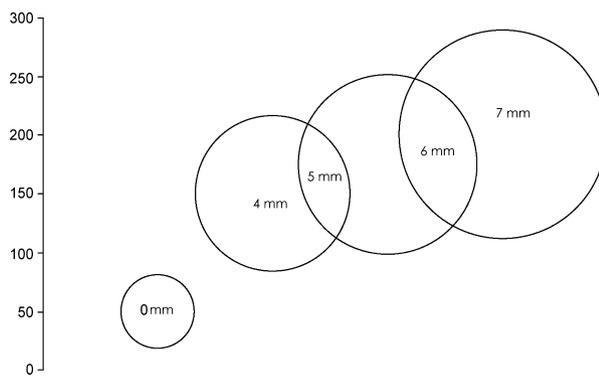


Fig. 4. Circles depict the relationship of mean maximum force from different advancement positions; numbers not within the same circle are statistically significant, $p < 0.05$.

and 198.2 ± 53.7 N at 7-mm mandibular protrusion, respectively.

Table 2 shows comparison of the voluntary force magnitudes produced at different mandibular protrusive positions. At P0, the retraction force was statistically significantly less ($p < 0.05$) than that produced from all other positions (Fig. 4). By advancing the mandible 4 mm (P4), the assessed values showed a statistical significant difference ($p < 0.05$) compared with all positions except P5. In the position 5 mm anterior to centric occlusion (P5), the pull back strength showed statistical significant difference ($p < 0.05$) compared with P0 and P7. At P6 position, the retraction force showed statistical significant difference ($p < 0.05$) compared with P0 and P4. In the most anterior evaluated position of the lower jaw (P7), the retraction force showed statistical significant difference ($p < 0.05$) compared with P0, P4, and P5.

Discussion

A functional appliance fixed by TADs in the mental foramen region would have the advantage of possibly increasing the skeletal component by avoiding dental side effects in the lower jaw that occur with any teeth-borne removable or fixed functional appliance, thus improving esthetics and decreasing the need for surgery or camouflage therapy in borderline skeletal Class II adult cases. As this bone-borne functional appliance would be fixed to bone by means of osteosynthesis or mini-screws, the stability of the appliance would be greatly affected by the forces created by contractions of the voluntarily during daytime or unconsciously at night. Therefore, we aimed to identify the mean maximum retrusive forces produced by the mandible to a tension/compression load cell system.

The force of retrusion from centric occlusion (P0) was used as baseline value and to compare the results with previous studies. The value for the P0 position 63.3 ± 18.3 N was less than the maximum voluntary retrusive force reported by Clark and Adler (22) of 175.5 ± 40.2 N, but was around twice that reported by Marklund and Molin (18) of 32 ± 12 N. Clark and Adler (22) claimed that their results were higher than Marklund and Molin (18) results, because of better internal adjustment of the splint and the distribution of the load along the entire lingual aspect of bone and teeth. In the study of Marklund and Molin (18), subjects could have had premature contact between some teeth and the splint, which could limit the extent of maximal force exerted because of pain. In this study, the splints were individually fabricated and checked before measurements were performed, and any premature contact, functional interference, or tooth contact causing pain to the subjects or altering the respective jaw movements were eliminated. No subject reported dental pain or discomfort during the test procedure.

Stepwise advancement was found to produce more growth compared with the single-step advancement for the correction of skeletal class II malocclusion (24, 25), and a 4 mm of initial advancement showed clinical efficiency in correction of skeletal class II malocclusion (5).

Therefore, 4 mm anterior position was chosen as the next level of assessment.

An important finding of this study was the progressive increase in the mean maximum force as the retrusion distance increased from 0 to 7 mm (Fig. 3). It was found that maximum active tension can be developed at optimum sarcomere length but decreases with greater and shorter lengths (26). Owing to the fact that the particular arrangement of the sarcomeres within the muscle may vary, the functional capabilities of the whole muscle may be different from those of the sarcomeres (27). Studies relating the biting force to vertical dimension showed that this behaves in a different way than would be expected from muscle stretching with increased opening. It is expected that the force would reach a single peak and then decrease consistently, yet the force increased on maximum biting, reaching two peaks with increased occlusal vertical dimension (14). Likewise it was expected, in this study, that the increase in the muscle length, by advancing the mandible, would improve the

mechanical advantage of the retrusion muscles helped by the stretched soft tissue and thus would have more force compared with P0, reaching a peak force after which it would decrease. A possible explanation for the steady increase in force is that the muscle had not reached its peak capability. This might be due to the limitation of movement imposed by the posterior ligaments of the condyle, or because of lateral pterygoid muscle's limited amount of maximum shortening, thus preventing protrusion of the mandible beyond its normal limit (28).

In general, a splinted Herbst appliance raises the bite by around 4 mm in the vertical dimension, whereas in this study, the thickness of the acrylic splints was kept to a minimum with an average increase in interincisal distance of $6.3 \text{ mm} \pm 1.7$. This would decrease the bite component of retrusion and could explain the lower force produced than in the study of Clark and Adler (22) whose interocclusal distance was increased on average by 15 mm. Another important factor that influences the accuracy of the

Table 2. Bonferroni test for multiple comparison of mean differences in maximum retrusive force, in newtons, at each distance

	(I) Position	(J) Position	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
						Lower bound	Upper bound
Bonferroni	0	4	-69.55*	14.02	0.000	-109.97	-29.13
		5	-89.67*	14.02	0.000	-130.09	-49.25
		6	-112.47*	14.02	0.000	-152.89	-72.05
		7	-134.87*	14.02	0.000	-175.29	-94.45
	4	0	69.55*	14.02	0.000	29.13	109.97
		5	-20.12	14.02	1.000	-60.54	20.30
		6	-42.92*	14.02	0.030	-83.34	-2.50
		7	-65.33*	14.02	0.000	-105.75	-24.91
	5	0	89.67*	14.02	0.000	49.25	130.09
		4	20.12	14.02	1.000	-20.30	60.54
		6	-22.80	14.02	1.000	-63.22	17.62
		7	-45.20*	14.02	0.018	-85.62	-4.78
6	0	112.47*	14.02	0.000	72.05	152.89	
	4	42.92*	14.02	0.030	2.50	83.34	
	5	22.80	14.02	1.000	-17.62	63.22	
	7	-22.40	14.02	1.000	-62.82	18.02	
7	0	134.87*	14.02	0.000	94.45	175.29	
	4	65.33*	14.02	0.000	24.91	105.75	
	5	45.20*	14.02	0.018	4.78	85.62	
	6	22.40	14.02	1.000	-18.02	62.82	

results is the range of freedom that was given for the movement of the mandible during retrusion which could simulate that produced in the normal situation. There was no head frame to hold the head steadily in place, and the subjects were allowed free head movement, also the flexible thread connecting the load cell to the mandibular splint allowed unrestricted mandibular movement rather than the otherwise rigid connection used in the previous studies (18, 22).

The effect of mandibular advancement on muscle activities is well documented in the literature. Fitting functional appliances on monkeys was associated with statistically significant decrease in postural electromyogram (EMG) activity of the masticatory muscles. The decreased postural EMG activity was maintained for approximately 6 weeks and then gradually returned toward pre-appliance levels during a subsequent 6-week period of observation (29). Similarly, a progressive mandibular advancement using Herbst appliance in monkeys showed that the statistically significant bone formation in the glenoid fossa and the increases in mandibular length were associated with decreased postural EMG activity in the superior and inferior heads of the lateral pterygoid, the masseter, and the anterior digastric muscles (30).

Some of the limitations of this study involved the inability of the measuring device to identify the exact direction of the retraction force or distinguish the stronger side (right or left), neither could it recognize the nature of the force: whether pure retrusion or with some closing force component. The data were derived from only 18 subjects; the range of forces identified at each retrusion distance reflects the wide individual variation within and between subjects.

Given the high forces found in this study on mandibular retrusion, single mini- and osteosynthesis screws commonly used nowadays in orthodontics might not withstand this voluntary pull back forces (31–33), and thus, the knowledge of bone characteristics in potential insertion sites is of great importance (Fig. 1; 34). Multiple mini-screws connected by some sort of a plate could deliver a system that might withstand such high

forces. Cornelis et al. (35) utilized surgical mini-plates to provide temporary skeletal anchorage in the maxilla and mandible and concluded that it may be considered ‘a safe and effective adjunct to orthodontic treatment’.

Conclusion

It was important to identify the magnitude of the force exerted by muscles during voluntary maximum retrusion movement from different advancement positions. Interestingly, there was a proportionately progressive increase in the mean maximum force as the retrusion distance increased from 0 to 7 mm. High forces ranged from 132.9 N at 4 mm to 198.2 N at 7 mm mandibular advancement were measured. Such range of high forces might be important to consider when planning to design a functional appliance having a mandibular bone-borne support.

Clinical relevance

All functional appliances for correction of skeletal Class II malocclusion usually lead, in different degrees, to proclination of the lower incisors, and their stability may be affected by the retrusive mandibular forces produced by masticatory muscles. Possible development of functional appliances anchored to bone by temporary anchorage devices would prevent these dental side effects and would additionally increase the intended skeletal effects for skeletal Class II correction, especially in border line adult cases. But bone-borne anchorage must however be able to withstand possible mandibular retraction forces. Mean maximum voluntary retrusive forces increased proportionally with increasing mandibular advancement distance and reached values up to almost 200 N at 7 mm of mandibular protrusion.

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