



Effects of rehabilitation with complete dentures on bite force and electromyography of jaw and neck muscles and the correlation with occlusal vertical dimension

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Abstract

Objectives The purpose of this study was to assess the effects of oral rehabilitation with complete dentures on bite force and electromyography of the suprahyoid and sternocleidomastoid muscles, and their correlation with occlusal vertical dimension (OVD). The research questions were “What are the effects of rehabilitation with complete dentures on bite force and electromyography of suprahyoid and sternocleidomastoid muscles, and how are they correlated with OVD?”

Materials and methods Patients who are wearers of unsatisfactory removable complete dentures were attended in three sessions (T0, T1, and T2). At T0, while the patients still wore the old dentures, they were submitted to bite force and surface electromyographic exams of the suprahyoid and sternocleidomastoid muscles. These exams were repeated, and the OVD was measured while the patients wore their old and new prostheses, 30 days after insertion of the new prosthesis (T1). The exams were repeated 100 days after the insertion of the new prosthesis (T2). The data were submitted to the Shapiro-Wilk normality test, analysis of variance (ANOVA), and Pearson correlation and linear regression, all with 5% significance.

Results Fifteen patients participated in the study. No statistically significant difference was observed for bite force or electromyography in T0, T1, or T2. However, the correlation and regression tests showed important interactions between the OVD and maximum voluntary occlusal bite force, as well as the OVD and electromyography during deglutition for the suprahyoid muscles.

Conclusion Rehabilitation did not impact bite force nor the activity of the assessed muscles (electromyography). On the other hand, OVD was shown to be an important factor for bite force, and deglutition of water after rehabilitation.

Clinical relevance This study shows what are the influences of rehabilitation on oral functions and reinforces the importance of corrected reestablishment of OVD because it has been found to be an important factor for bite force and electromyography during deglutition.

Keywords Mouth rehabilitation · Stomatognathic system · Electromyography · Skeletal muscle · Bite force · Vertical dimension

Introduction

According to the World Health Organization, the increase in the population of people over 60 years old has occurred more rapidly than any other age group in most countries [1]. Aging

leads to decreased strength, speed, stability, coordination, and performance of whole-body organs and systems [2], which suggests that the elderly take longer to eat meals and have less efficient, more easily fatigued swallowing muscles [3]. In addition, the elderly have significantly higher deglutition duration and total time for liquid consumption in comparison with younger people [4].

Many elderlies are rehabilitated with removable complete dentures, which provide improvements of masticatory function and positively impact the quality of life when they are well fabricated and adapted [5]. Conversely, the use of a badly adapted prosthesis is related to social discomfort, mainly during meals [5], limiting them to softer and pasty foods [6] which may present a higher risk of nutrition deficiency [7].

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It is known that elderly people with poor health and tooth loss tend to have a more rapidly reduced bite force [8]. Bite force is a physiological characteristic related to quality of life and is capable of influencing nutritional quality of an individual because it is related to masticatory efficiency, food grinding, and digestion [9]. Besides the analysis of bite force, muscle characteristics can be studied by using electromyography (EMG), which is used by many researchers to assess the effects of rehabilitation, changes of muscle behavior, and efficiency of treatments [10–14].

Muscle tonus and extension can be modified by recovery of the occlusal vertical dimension (OVD) [15], which can decrease during the use of a prosthesis due to the progressive occlusal wear of the artificial teeth [16] and alveolar ridge bone resorption [17]. It is expected that the OVD will be recovered when a new prosthesis is inserted [18]. Several authors have studied the effects of oral rehabilitation on the masticatory system [5, 10, 11, 19–21], which requires the harmonic contraction of many masticatory, head, and neck muscles [22]. An example of the functional connection between the neck and masticatory muscles is the fact that the sternocleidomastoid muscle is activated when masticatory load is increased [23]. The digastric, mylohyoid, stylohyoid, and geniohyoid muscles compose the suprahyoid muscle group [24]. They participate in the movement of deglutition [25] and the beginning of the suction movement [26], as well as show activation during the masticatory function [25, 27], which varies according to the consistency of food [27]. These facts led this study to assess the behavior of these muscles in different oral functions before and after the rehabilitation.

Thus, the aim of this study was to assess the effects of oral rehabilitation with complete dentures on bite force and electromyography of the suprahyoid and sternocleidomastoid muscles, and their correlation with OVD. The hypotheses were that (1) bite force would increase after rehabilitation, (2) there would be significant changes of the electromyography of the suprahyoid and sternocleidomastoid muscles, and (3) there would be a correlation between the changes of OVD and bite force, as well as changes of OVD and electromyography.

Materials and methods

Participants

Patients from the Complete Dentures Clinic of São Paulo State University (UNESP), Araçatuba Campus, were verbally invited to participate in the study. The patients needed to be wearers of unsatisfactory bimaxillary removable complete dentures for at least 5 years, and be enrolled as a patient of UNESP for rehabilitation with a new prosthesis of the same type. The patients were selected according to the inclusion/

exclusion criteria described in the previously published study of de Caxias et al. [28].

The selected patients received verbal and written information about the prosthetic rehabilitation and the research, and signed an informed consent form. This study was approved by the Human Research Ethics Committee of the Araçatuba Dental School (UNESP) (opinion number 66699617.4.000.5420). All procedures were carried out according to the Criteria of Ethics in Research with Humans and in accordance with the Declaration of Helsinki [29].

Study design

This observational longitudinal clinical study was divided in three sessions: before (T0), 30 days (T1), and 100 days (T2) after insertion of a new prosthesis. At T0, the patients answered Axis I of the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) questionnaire [30]. The bite force assessments and EMG exams of the suprahyoid and sternocleidomastoid muscles were performed while the patients still wore their old prostheses (maxillary and mandibular). At T1, the abovementioned assessments were repeated, except the application of the RDC/TMD, and the OVD was measured while the patients wore their old and new prostheses. At T2, the bite force assessment and electromyographic exams were repeated. As a reference to start counting the time before T1 and T2, the prostheses were considered inserted when no adjustment was necessary in their occlusal surfaces or basis.

RDC/TMD questionnaire

The RDC/TMD questionnaire was used for the selection of patients, as well as to collect sociodemographic data. Axis I of the RDC/TMD has 31 questions with and without subscales. The questions are related to the perception of own health, TMD symptoms, bruxism, traumas, psychological status, and sociodemographic data [30]. The questionnaire was applied by an examiner who read the questions to all the patients. The patients answered the questions verbally because many patients were illiterate.

Bite force assessment

The bite force assessments were made using an IDDK dynamometer (Kratos – Equipamentos Industriais Ltda, Cotia, Brazil) with a 15-mm thickness and 1000 N. The examiner received judicious training to become familiarized with the equipment, and the patients were also familiarized.

The recordings were made on the left and right first molars. Each recording was performed 3 times on each molar. The patients were instructed to bite the transducer with maximum force for 5 ± 2 s, with 2-min intervals between each recording.

The highest value from each recording of each molar was selected for analysis [31].

Electromyographic exams of the suprahyoid and sternocleidomastoid muscles

A MyosystemBr1_P84 and software MyosystemBr1 3.5 (DataHominis Tecnologia Ltda., Uberlândia, Brazil) were used to process and visualize the electromyographic surface signals. The connector of the electromyograph had constant current tension output of $\pm 12\text{ V}$ @ $\pm 100\text{ mA}$ and common-mode rejection ratio of 112 dB @ 60 dB. It had protection against over tensions and low pass filter for elimination of noises from 5 Hz to 5 KHz. Two dischargeable round electrodes (Meditrace 100, Covidien Ilc, USA) made of polyethylene foam with medical adhesive, Ag/AgCl double contact, and adherent hydrogel with low impedance were used to record the electromyographic signals [28] in each muscle. The electrodes were placed with 20 mm inter-electrode distance.

For the suprahyoid muscles, the electrodes were placed bilaterally below the mental region, after the inferior border of the mandible, following the fibers of the anterior digastric muscle [32]. For the sternocleidomastoid muscles, electrodes were placed bilaterally approximately at 3 cm behind the mandible angle/ear lobe following the direction of the muscle fibers [33]. The electrodes and wires were fixed with an adhesive tape to avoid movements during the exams [34]. The connection was tested, the gain was adjusted, and the necessary adjustments were made before the signal recording. The frequency of acquisition was adjusted to 2400 Hz, the filter was adjusted to 1000 Hz, and the electrode gain was equal $\times 20$. Before placement of the electrodes, oil from the skin was removed by washing the neck and submandibular region (the area where they were placed) with astringent soap and gentle rubbing with cotton soaked with 70% alcohol, aiming to reduce impedance and improve signal conductivity [15, 35]. A grounded electrode was positioned on the wrist [15] to minimize interference [28]. The patient remained seated on a chair and was asked to be relaxed while keeping both feet on floor, hands on their lap, and their head in a position that kept the Frankfurt plane parallel to the floor [21].

The electromyographic signals were recorded during mandibular rest for 10 s, habitual maximum intercuspation (HMI) for 5 s, HMI with thin plastic film folded in three (Parafilm M, Bemis Company Inc., Neenah, USA) for 5 s, mastication of 3 g of raisins for 10 s, mastication of 3 g of peanuts for 10 s, suction of water with a straw (10 mm length \times 3 mm thickness) for 6 s, and deglutition of water (3 times and the highest value was noted) [35]. For the analysis, the electric signals were analogically amplified and bandpass filtered (15–1200 Hz). The positions of the electrodes at T0 were drawn on a template by using a transparent A4 acetate sheet (Filiperson Ind. De Papéis Ltda., Rio de Janeiro, Brazil),

which was used posteriorly to place the electrodes on the same area at T1 and T2. The mean of the electromyographic signals of the suprahyoid muscles was calculated and used for analysis. The electromyography of the right and left sternocleidomastoid was analyzed separately. The software presented the root mean square (RMS) of the electromyographic signals in microvolts (μV).

OVD measurements

The caliper method was used to measure the OVD. The patients were asked to wear their old prostheses and were instructed to maintain the maximum intercuspation without contracting the lip muscles. A 1-mm-thick permanent marker (Pilot Pen do Brazil S.A., São Paulo, Brazil) was used to mark two dots on their faces: one in the mental region and the other on the tip of the nose. Then, the distance between the two dots was recorded using a dry-end compass with a locking system (ICE- Instrumentos Cirúrgicos Esmeralda, Cajamar Brazil) [36], and the measurement was made using a millimeter ruler (ICE- Instrumentos Cirúrgicos Esmeralda, Cajamar, Brazil). The patient was then instructed to immediately wear the new prosthesis, following the same instructions, and the measurement was repeated. The measurements obtained with the old and new prostheses were noted, and the difference was calculated in millimeters.

Prosthesis fabrication

The prostheses were fabricated with acrylic resin according to the technique recommended by Zarb et al. [37].

Process reliability

The reliability of the acquisition process (method error: Se) was calculated with the Dahlberg formula ($Se = \sqrt{\sum (d^2)/2n}$), where d represented the differences between data acquisition in the patients and n was the number of double acquisitions [38]. The percentage errors were calculated by the formula $\% = (Se/\text{mean}) \times 100$ [38]. The mean represented the mean value of the first and second acquisition [38]. The method errors of bite force and electromyography measurements were calculated with 5 patients with 7 days between the measurements.

Data normalization

The value of the HMI with Parafilm M task was used as reference for data normalization. The value acquired during first HMI with Parafilm M (for each participant, each muscle, and in the first session) was considered as 100%, and the percentage of this value was calculated for each movement.

Statistical analysis

The sample size estimation was made using the G*Power 3.1.9 software (Dusseldorf University, Germany) with the statistical power of 0.8 and 5% p value with data from a pilot study. The estimated sample required to obtain reliable results was 8 patients.

The R software (version 3.5.3; R Foundation for Statistical Computing, Austria) was used for statistical analysis. The normality was assessed with the Shapiro-Wilk test, and a normal distribution was shown.

The bite force and electromyographic data were analyzed by repeated measures analysis of variance (ANOVA). The bite force was analyzed by side (right and left) and session (T0, T1, and T2) as within-subject factors. The EMG of the suprahyoid muscles was analyzed by session (T0, T1, and T2) as within-subject factor. The electromyography of the sternocleidomastoids was analyzed by side (right and left) and session (T0, T1, and T2) as within-subject factors.

Pearson's correlation tests were used to analyze the correlation between the difference of the OVD and bite force and between the difference of the OVD and electromyography of the suprahyoid and sternocleidomastoid muscles. Linear regression was used to assess the influence of difference of the OVD on bite force and electromyography with the old and new prostheses. Significance level was 5% in all analyses.

Results

Twenty-one patients met the inclusion criteria and were selected to participate in the study; however, 6 did not complete the three sessions due to personal or health reasons. Thus, fifteen patients (13 women and 2 men) with a mean age of 67.7 (with a range from 50 to 87 years old) who had worn the existing prostheses for a mean age of 11.21 years (ranging from 5 to 30 years) were included in the study.

Process reliability

A slight difference was found between the first and second session for electromyography (7.6%), and for bite force, the means of the three bites for each side were calculated (1.04%).

Bite force

Two-way ANOVA demonstrated no statistically significant difference in bite force for the right and left side among the three sessions ($p = 0.176$). Table 1 shows the values found for bite force for the right and left side in the different sessions (T0, T1, and T2).

Electromyography

For electromyographic assessments of the suprahyoid muscles, one-way ANOVA did not demonstrate statistically significant difference for any of the functional movements among the three sessions: rest ($p = 0.331$), HMI ($p = 0.728$), mastication of raisins ($p = 0.050$), mastication of peanuts ($p = 0.350$), suction ($p = 0.825$), and deglutition ($p = 0.370$).

For electromyographic assessments of the sternocleidomastoid muscles, two-way ANOVA did not demonstrate statistically significant difference for any of the functional movements among the three sessions: rest ($p = 0.359$), HMI ($p = 0.576$), mastication of raisins ($p = 0.402$), mastication of peanuts ($p = 0.050$), suction ($p = 0.999$), and deglutition ($p = 0.561$). Table 2 shows the normalized mean values of the suprahyoid and sternocleidomastoid muscles in the different sessions (T0, T1, and T2) and functional movements.

OVD

Of the 15 patients, 13 had increases of OVD after rehabilitation with the new prosthesis, 1 patient had the same measurement with both pairs of prostheses, and 1 patient had missing data. The mean increase of OVD was 3.6 mm (varying from 0 to 8 mm).

Correlation analysis and linear regression

Pearson's correlation analysis and linear regression demonstrated positive correlation between the OVD and bite force for the right molar at T2 and the left molar at T1 and T2 (Table 3), and negative correlation between the OVD and electromyography of the suprahyoid muscles during deglutition at T2 ($R = -0.694$; p value 0.006; R^2 0.482).

Discussion

This study showed that rehabilitation with new removable complete dentures did not increase bite force, nor did it cause significant changes of electromyography of the suprahyoid and sternocleidomastoid muscles; thus, hypotheses 1 and 2 were rejected. Positive correlation found between changes of OVD and bite force, and the electromyography was negatively correlated with the changes of OVD; thus, hypothesis 3 was accepted.

Although statistically significant difference was not found for bite force, it could be observed that the values decreased at T1 and increased at T2. This result is in accordance with a previous study in which no significant difference was found for bite force between old and new prostheses at 2 months post-rehabilitation [39], and a study that found a decrease of bite force with no significant difference shortly after new prosthesis implantation [40]. However, this second study, contrary

Table 1 Mean (SD) of bite force values, in Newtons, in right and left side in different sessions (T0, T1, T2)

Right side			Left Side		
T0	T1	T2	T0	T1	T2
61.2 (32.3)	53.3 (15.4)	57.7 (29.5)	51.5 (32.3)	44.5 (15.4)	53.3 (29.5)

SD standard deviation

to the present results, found an increase of bite force 1 month after the rehabilitation [40]. It is important to emphasize that bite force is influenced by different physiological and non-physiological factors, such as muscle pain and/or inflammation in temporomandibular joints [41], facial osteoporosis [42], gender, age, number of teeth, and educational level, which are related to oral health status [43] and which may influence the assessments in different elderly populations.

As well as for bite force, the electromyographic exams did not show statistically significant difference. The absence of difference may be due to the short-term follow-up, but on the other hand, a previous study with a very similar group of patients and the same assessment periods showed statistically significant difference in electromyography of the orbicularis oris muscle [28]. This infers that differences in electric activity can happen in some groups of muscles, but be absent in other groups, or that different muscles need different times to show significant changes after oral rehabilitation with complete dentures. A clinical study with a longer follow-up would be capable of accepting or rejecting this hypothesis. The literature lacks studies on the influence of rehabilitation with complete dentures in submandibular and neck muscles. According to a literature search, only one study examined the EMG of SCM in denture wearers, but no jaw function was assessed and there was no assessment of oral rehabilitation [44]. Another study compared the electromyography of the suprahyoid muscles of dentate and edentulous individuals during oral functions [45], and yet another study assessed the electromyography of the suprahyoid and other muscles in denture wearers, but both without assessment before or after oral rehabilitation. Thus, according to the knowledge of the authors, the present study is the first to compare the electromyography of the suprahyoid and sternocleidomastoid muscles before and after rehabilitation with complete dentures.

This study showed positive correlation of bite force and OVD, and negative correlation of electromyography and OVD, emphasizing its relevance in oral rehabilitation with complete dentures. A correct OVD in complete denture rehabilitation leads to muscle relaxation because of length reprogramming and muscular tonus [15]. Müller et al. [40] explained that changes of OVD, which occurred in most of the patients in this study, have effects on muscle capacity to exert maximum extensions in the short-term and less immediately. These authors explained that “the immediate effect is a function of the optimal working length of the sarcomeres” [40].

The same authors cite the work of Goldspink [46], which said that “the less immediate effect results from the capacity of muscle to ‘graft in’ new sarcomeres ‘in series’ on elongated muscles, thus restoring the optimal sarcomere length” [40]. Goldspink [46] emphasized that this mechanism of sarcomere length adjustment must be taken into consideration by dentistry, due to adaptation of masticatory muscles to a new functional length in procedures that change vertical dimensions.

Several techniques are used to assess OVD loss [47, 48], such as pre-treatment record, incisor height measurement, phonetic evaluation, patient relaxation, assessment of facial appearance, radiographic evaluation, neuromuscular evaluation [47], and deglutition, among others [48]. The clinic where the prostheses were fabricated in the present study used combined techniques, such as Pleasure’s [49] and phonetic, to reinforce the precision of OVD restoration. Regarding OVD gain measurement, the caliper method was chosen because it was found to be more accurate than the Willis gauge method [36]. Both methods are easy and quick, but in addition, caliper has the advantage of being less expensive [36]. Regardless of the method used to determine OVD in rehabilitation, it is important to perform an accurate restoration since inadequate OVD leads to several consequences for masticatory function and esthetics, causing treatment failure. Some consequences of reduced OVD are mandibular projection; circumoral muscle flabbiness [50] with a longer, flatter upper lip and a shorter lower lip; morphological alterations of temporomandibular joints [51]; increased nasolabial crease [52]; and angular cheilitis [53]. On the other hand, an excessively increased OVD may lead to joint and muscle pain, speech problems, difficulty in swallowing and mastication, bone resorption, tooth sensitivity and abnormal wear in dentate individuals, appearance of an elongated face, and facial expression of fatigue [54].

This study emphasized the importance of OVD in rehabilitation with complete dentures. This was supported by the results that demonstrated positive moderate correlation between OVD and bite force at T1 and T2, showing that a considerable part of bite force was explained by OVD, which can be verified by the values of p and R^2 . Negative moderate correlation was found for electromyography during deglutition for suprahyoid muscles at T2, showing that, as well as for maximum voluntary occlusal bite force, a considerable part of electromyography was explained by the OVD (p and R^2). The results of this study can be used as a scientific reference of the importance of correct OVD restoration, since it was

Table 2 Normalized mean values (SD) of suprahyoid and sternocleidomastoid muscles in different sessions (T0, T1, and T2) and functional movements

Muscle	Rest			HMI			Mastication of raisins		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
Suprahyoids	45.5 (37.6)	61.8 (26.3)	63.3 (41.7)	141.3 (127.3)	119.6 (63.3)	118.3 (57.8)	254.4 (143.9)	268.8 (94.9)	418.2 (285.06)
SCM	78.70 (35.2)	71.96 (24.6)	68.95 (36.9)	70.33 (38.1)	74.16 (26.3)	88.64 (22.1)	97.92 (32.3)	93.10 (28.3)	111.17 (30.8)
Left	77.03 (36.8)	78.70 (35.2)	71.96 (24.6)	68.95 (36.9)	70.33 (38.1)	74.16 (26.3)	88.64 (22.1)	97.92 (32.5)	93.10 (28.3)
Muscle	Mastication of peanuts			Suction			Deglutition		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
Suprahyoids	601 (1052.3)	290.9 (160.6)	340.5 (168.2)	253.60 (338.4)	229 (153.1)	200 (172.7)	234.1 (204.1)	236.1 (97.2)	303.1 (130.8)
SCM	100.68 (66.5)	86.23 (21.4)	105.88 (49.5)	78.06 (33.1)	85.15 (45.3)	80.99 (52.3)	128.62 (89.7)	117.93 (53.3)	101.04 (50.2)
Left	111.17 (30.8)	100.68 (66.5)	86.23 (21.4)	88.23 (45)	78.06 (33.1)	85.15 (45.3)	100.52 (53.3)	128.62 (89.7)	117.93 (53.3)

SD standard deviation, SCM sternocleidomastoid

Table 3 Pearson's correlation analysis and linear regression of OVD and bite force on right and left molars at different sessions

Side	Session	<i>R</i>	<i>p</i> value	<i>R</i> ²
Left molar	T1	0.538	0.047	0.2896
	T2	0.645	0.0127	0.4161
Right molar	T2	0.537	0.0474	0.289

R correlation coefficient, *R*² determination coefficient

demonstrated to have significant influence on several functional movements.

The absence of a control group can be cited as a limitation of this study. Another limitation is the lack of control over the use of the prosthesis during the adaptation period. This control was based on patient reports only, which could not be confirmed. A study using a digital appliance attached to the prosthesis would be capable of confirming the effects of oral rehabilitation on functional movements, since the use of the prosthesis can be monitored. Future studies comparing different OVD measurements and different oral rehabilitation methods can provide further information about bite force and electromyography of the suprahyoid and sternocleidomastoid muscles in elderly patients. As well, further studies assessing the correlation of OVD and electromyography of different head and neck muscles can confirm the importance of precise OVD recovery, bringing more scientific basis for clinicians during restorative treatments.

Conclusion

The rehabilitation did not impact bite force nor the activity of the assessed muscles (electromyography). On the other hand, OVD was shown to be an important factor for bite force and deglutition of water after rehabilitation, due to the correlations that were found.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the Human Research Ethics Committee of the Araçatuba Dental School (UNESP) (opinion number 66699617.4.000.5420). All procedures were carried out according to the Criteria of Ethics in Research with Humans and in accordance with the Declaration of Helsinki.

Informed consent Informed consent was obtained from all individual participants included in the study.

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