Bilateral Variation of the Silent Period and Isotonic and Isometric Activity of Jaw Closing Muscles

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Summary

The aim of this study was: 1. To measure latency and duration of the silent period elicited in an open-close-clench cycle in individuals with all teeth and normal occlusion. 2. To compare the latency and duration of a silent period between the different elevator muscles examined and the symmetry of the reflex responses. 3. To analyze isotonic and isometric muscle activity in open-close-clench cycles and to compare it to the maximum voluntary myoelectric activity.

Silent periods were registered and measured in 62 individuals with normal occlusion on the EMGA-1 apparatus. Ten registrations of an open-close-clench cycle was made for each participant to elicit silent periods. Signals from the right and left anterior temporal and left and right masseter muscles were recorded by surface electromyography during 240-300 ms.

Silent periods had a latency of 12.5-12.9 ms after the occlusal contact and had only a single short inhibitory pause with complete inhibition of motoneurons. The duration of the silent period was 20.1-21.1 ms. There were no statistically significant differences ($p>0.05$) of the silent period latency and duration between the examined muscles and the left and the right side. Isotonic muscle activity was equal to isometric muscle activity for each muscle in open-close-clench cycles. The mean isotonic muscle activity was spontaneously constant between open-close-clench cycles and was approximately 60% to 70% of the mean muscle activity during maximum voluntary clencing.

The reflex was considered oligosynaptic. The reflex was fully symmetrical and of equal latency and duration between the examined muscles. Stimulation of the primary mechanoreceptor afferents in periodontal ligament by tensile forces generated between occlusal tables of opposing teeth and/or vibration of the unique teeth contact (normal occlusion) and consequent stimulation of mechanoreceptors in temporomandibular joint, tendons or muscles by vibration could be responsible for the reflex.

Key words: *silent period, symmetry, normal occlusion, jaw closing muscles, open-close-clench cycle, isotonic and isometric activity.*

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Introduction

The silent period, or an inhibitory reflex, is defined as a transient cessation or complete inhibition of motoneuron activity following stimulus in a contracting muscle (1-3). In masticatory elevator muscles the silent period commences after functional contacts of the opposing teeth or after some other stimulus in oral and perioral region during the muscle contraction (1-3).

Hoffman first described the silent period in men in 1919 (4), after he had stimulated muscles of an upper limb by electrical impulses during contraction.

Schaerer et al. in 1967 (5) and Brenman et al. in 1968 (6) noticed the appearance of a transient pause in electrical activity of elevator muscles during mastication after the tooth contact. Alghren (3) was the first who defined this inhibitory pause and he supposed it was caused by inhibitory impulses of the afferents from periodontal ligament.

Later, it was discussed in the literature that the silent period in the jaw elevator muscle is multicausal, as various stimuli elicit silent periods, e.g. occlusal contacts (1-5), tap to the menton (7-9), or to the tooth (10-11), direct mechanical (12) or electrical stimulation of the oral (13) and perioral regions (14), and the tooth pulp (15), the only condition is that the muscle is contracted before the stimulus is applied. This means that stimulation of afferents from various receptors in oral and perioral region during muscle contraction can elicit a silent period. Also, the duration of the silent period can be slightly modulated through the input from the receptors at remote sites in the body (16).

The silent period received a lot of interest in dentistry since it was claimed that it has longer duration in patients with craniomandibular dysfunction than in healthy individuals and that it may be a tool of diagnostic and prognostic interest (8, 16, 17). On the contrary, some other studies could not prove the prolongation of the silent period in craniomandibular dysfunction patients and even claimed that the duration of the silent period is shorter in craniomandibular dysfunction patients (10, 14, 18). The upper limits of a prolonged silent period also vary from study to study, and so do the methods used for silent period eliciting (6, 7, 16, 18-20). The real importance and mechanisms of this inhibitory reflex have still not yet been elucidated.

However, there have also been some questions raised on possible effects of the testing methods on the duration of the silent period and thus on the reliability of the silent period data obtained (8, 21). It has been established that the duration of a silent period varies, depending on the method used (i.e. depending on which receptor is stimulated to elicit the silent period), the force of the stimulus applied (9), the reticular formation excitement and the level of previous muscle activity, i.e. the firing rate of motoneurons (14, 19, 20).

Significant bilateral differences in various reflex measurements, particularly in latency, have been related to pathology. Normal values for the latency and duration of the silent period, as well as underlying mechanisms depending on the testing method for eliciting the reflex, are still discussed throughout the literature.

Therefore the aims of this study were: 1. To measure the silent period latency and the duration in open-close-clench cycles in healthy individuals with normal occlusion of the upper and lower teeth, for the right and left anterior temporal and right and left masseter muscles 2. To determine muscle isotonic and isometric activity in the open-close-clench cycles and to compare it to the muscle activity during the maximum voluntary clenching 3. To compare the latency and duration of the silent period, as well as to compare isotonic and isometric activity between the muscles and the left and the right side.

Patients and Methods

The participants were chosen from among students of the School of Dental Medicine, University of Zagreb, Croatia. The participants had to fulfill the following criteria: 1. All the teeth in both jaws had to be present. 2. Occlusion had to be normal (Angle Class I). 3. No previous history of orthodontic treatment. 4. No previous history of myofascial pain syndrome. 5. No history of any disease that affected neuromuscular performance. 6. Not taking any medications and not currently undergoing treatment for any medical problem. 7. Weight and height had to match the normal limits for the age and sex group.

Among the students, 120 of them fulfiled the above mentioned criteria, but only 62 participated in the study. All of the subjects were fully informed of the experimental procedures before their consent was obtained. All the participants were aged between 19 and 26 years. There were 23 females and 39 males.

Electromyographic and audio signals were registered during open-close-clench tasks. They were asked to open the mouth and then to close the mouth suddenly so that the upper and the lower teeth come into intercuspal contact. In this way 10 open-close--clench cycles were performed for each individual. Participants also had to perform a task of maximum voluntary clenching in intercuspal position during a period of 2.4 seconds.

The registrations were performed with an EMGA-1 apparatus, which is a PC controlled multichannel system for simultaneous surface myoelectric and gnathosonic signal registration and analysis. The EMGA-1 device consists of 6 electromyographic and 2 audio amplifiers connected to a PC through an A/D converter with resolution of 8 bits. A special software "Medwin" was developed, to allow amplifier settings and adjustment, data acquisition and on or off line analysis (24).

Electromyographic amplifiers (imput impedance 100MΩ, CMRR>95dB at 50Hz, bandwidth 10-500 Hz, input noise < $2\mu V_{pp}$) were applied in different modes. Both, low- and high-pass filters are 2^{nd} Bessel type filters. The input sensitivity was set individually, from 0.5 to 2 mV_{pp}.

Gnathosonic signals were recorded with two electret microphones (type EU-6, sensitivity 10 mV/Pa at 1 kHz, diameter 9.5 mm). The microphones were connected to audio amplifiers (bandwidth 10 Hz to 4 kHz, 2nd order Bessel type filters). Low frequency cutoff for myoelectric signals was set at 10 Hz.

Due to different spectral contents, myoelectric and gnathosonic signals were digitized at different sampling rates (20kHz per channel for electromyographic and 60 kHz per channel for audio signals).

Duration of the recorded sequences could be changed from 240 ms to 2.4 sec and for the registration of open-close-clench k cycles the duration of 240 ms, or 300 ms was used.

Each record was triggered by the onset of the myoelectric isotonic activity of the right temporalis muscle. The trigger threshold was adjusted individually by the cursor, depending on the level of individual myoelectrical activity displayed on the screen.

The 6 simultaneously recorded signals were displayed on the PC screen in separate windows allowing visual control of each signal. The software "Medwin" allowed superimposing of the windows with audio or myoelectric signals.

After the visual control (if any record had an artifact, it was excluded), the signals were stored on the computer hard disk, or diskette for of-line analysis.

The software enables cursor measurements (time and voltage). In order to obtain better resolution (the best possible 4 ms), the time measurements (silent period latency and duration) were performed under the two or five time zoom-in option, mostly at the two times zoom-in.

Software enables direct calculation of root mean-square values or average voltages for the myoelectrical signals between the cursors, as well as the presentation of the frequency of the signal (number of points crossing the zero line).

Surface electromyographic disc electrodes (Ag/AgCl, diameter 8 mm) were placed 20 mm apart, using the standard positions for the anterior temporalis and masseter muscle, by means of flexible triangles, positioned along the Camper's line with circles cut out to mark the electrode position (22). Before the electrodes were placed, the skin was thoroughly cleaned by alcohol to reduce the skin impedance. Electrolitical jelly was used and the interelectrode impedance had to be less than 10 kΩ, which was checked by the software program. The ground electrode was placed on the wrist of the left arm.

The microphones for the occlusal sound registrations were placed on the skin over the most prominent part of the zygomatic bone by adhesive tape.

The electromyographic signals were recorded and stored on the disk for subsequent analysis from the 4 elevator masticatory muscles: right and left anterior temporal muscles (and right and left masseter muscles simultaneously with the audio signals from the occlusal contacts.

Silent periods were elicited in open-close-clench cycles. The open-close-clench cycle is defined as the cycle when an individual from open mouth position firmly closes the mouth and the teeth come into occlusal contact in habitual occlusal position. Following the latency after the occlusal contact, the silent period commenced in an electromyogram of the jaw elevator muscles.

The EMGA-1 device made it possible to superimpose the trace of an occlusal sound over the trace of muscle activity and to measure the duration of the signal or the mean voltage directly on the screen between the cursors, which was done at double zoom in.

All the measurements were made off-line, by one trained and experience examiner.

Isotonic muscle activity was defined as the muscle activity from the triggering of the records on the screen to the occlusal contact. Isometric activity is the muscle activity after the occlusal contact, although in this study it was measured after the end of the silent period to the end of the muscle activity on the screen. Average voltages during isotonic and isometric contraction in open-close-clench cycles were measured, as well as mean voltage from the isometric activity during maximum voluntary clenching.

The latency of the silent period was measured from the commencement of an occlusal sound trace to the peak of the last significant spike of muscle activity proceeding the inhibition (Figure 1A). The duration of the silent period was measured from the peak of the last significant spike proceeding the inhibition to the peak of the first significant spike as part of the ongoing muscle activity (Figure 1B).

Ten subsequent open-close-clench cycles were registered for each individual to the representative value of silent period parametars (22, 23).

From the data obtained statistical analysis was made. The ability to perform parametric test, normality of distribution was tested by the one-sample Kolmogorov-Smirnov test. Mean values (x) and standard deviations (SD) were calculated. MANOVA was used to test the difference for the silent period latency and duration between muscles and sides. T test was used to test the significance of the difference between the left and the right side muscles. ANOVA (Sheffe post hoc) was performed to test the difference between isotonic and isometric activity in open-close-clench cycles and maximum voluntary isometric activity during maximum clenching effort for each muscle. Coefficients of correlation were calculated between isotonic muscle activity and the duration of the silent period. Statistical analysis was conducted at 0.05 level of significance.

Results and Discussion

The mean values for the latency and duration of the silent period elicited in open-close-clench cycles are presented in the Table 1. Silent periods so obtained had one short inhibitory pause and the motoneuron inhibition was complete. The mean values for the latency ranged from 12.5 to 12.9 msec and the mean values for the duration ranged from 20.1 to 21.1 msec.

There were no statistically significant differences for the latency ($p>0.05$) and the duration ($p>0.05$) of the silent period between the examined muscles, or between the left and the right side, indicating the symmetry of the reflex (MANOVA analysis, Table 1).

The results of this study revealed that the silent periods had one short inhibitory pause and the motoneuron inhibition was complete.

Values for the latency and duration of the silent period resemble the results of other authors who elicited silent periods in an open-close-clench cycle (18, 23-27).

The latencies of the silent period elicited by menton tap are similar (17, 19), but the latencies of the silent period elicited by electrical stimulation of tooth pulp (15, 28) or the lower lip (20 ms) (14, 19-21) are longer, as well as the latencies of the silent period elicited by mechanical stimulation of the hard palate (50 msec) (12) or the skin over the masseter (54 msec) (29).

Motor nucleus of the Vth nerve is situated in the center of the pons. Olsson (30) divided the borderzone around the motor nucleus into 4 areas: intertrigeminal (NintV), supratrigeminal (NsV), medial (Mb) and ventral (Vb). The assumption is that the interneurons responsible for the inhibition of motoneurons are placed in the nucleus supratrigeminalis (NsV) and intertrigeminalis (NintV). As the nerve fibers from periodontal receptors are fast conductive and latencies of the silent period in the open-close-clench cycle obtained in this study are short, this reflex should be supposed as an oligosynaptic one, opposite to the latencies from the other sites (e.g. from oral mucous membrane (12), or tooth pulp (15, 28)) which have more synapses and/or longer conduction.

The interneurons in the supratrigeminal nucleus are considered as common inhibitory interneurons that mediate reflex inhibition of jaw-closing motor neurons from a variety of peripheral sources, as they receive the converging afferent inflow from stimulation of the supra and inferior alveolar nerve (31). The ongoing activity of the jaw musculature can be adjusted by altering the transmission from primary afferents to interneurons, as well as by modulation of the interneurons themselves (32). Mesencephalic nucleus is the site for the afferents from muscle spindles, which project directly to the motor neurons acting excitatory, but also the presence of periodontal low-threshold afferents in lower parts of mesencephalic nucleus has been proved (33). Interneurons in the supratrigeminal area receive projections from mesencephalic trigeminal low-threshold periodontal afferents and make inhibitory contacts with the jaw-closing motor neurons (33, 34).

As the latencies of the silent period in this study were short (12 ms), it could be supposed that tooth contact in open-close-clench cycle stimulate low-threshold periodontal afferents from mesencephalic nucleus, which project to the interneurons in the supratrigeminal area and from these interneurons to the jaw elevator motoneurons in pons. However, receptors in muscle spindles, muscle tendons or in temporomandibular joint also could play a part in eliciting the reflex, stimulated through the vibration when the teeth come into the occlusal contact and then projecting to the supratrigeminal nucleus. In any case the reflex should be considered olygosynaptic, for its short latency.

The duration of the silent period in this study was slightly longer compared to the results of Griffin and Munro (13 ms) (25, 26) and Freesmeyer (17-18 ms) (27), and is similar to the result of Chong-Shan and Hui-Yun (18). Freesmeyer (27) measured only inhibitory pause (not peak to peak activity) and Griffin and Munro (25, 26) measured the silent period duration on paper by a caliper with precision of 0.1 mm and therefore could not be sufficiently precise.

The results of this study show that in open-close-clench cycles of participants with normal and healthy occlusion (although the forces between opposite teeth and the jaw separation were not the same in all participants) only one silent period of short duration (approx. 20 msec) occured. If periodontal receptors were responsible for the reflex, then the occlusal forces of different strength, generated between the opposing teeth in an open-close-clench cycle stretched periodontal ligament along the long axes of the tooth (as all the participants had normal and healthy occlusion) and the receptors reacted to the tensile forces uniformly causing only one, short duration silent period in all the muscles examined and symmetrically on each side. (Table 1, Figure 2). If vibratory stimuli were responsible for the reflex, then vibration due to the upper and lower teeth contact could stimulate mechanoreceptors in muscles, tendons or the temporomandibular joint. Due to the uniform occlusal contact and the stable occlusion, the consequent vibrations were sudden and short, which resulted in only one, short duration silent period. Müller et al. (35) suggested that vibration is the most important factor for the inhibition of motoneurons (silent period) during mastication and that periodontal sensation, mandibular closing movement and the preload by the muscle at the onset of mastication play a minor role.

The duration of the silent period elicited by other methods (electrical stimulation, menton tap, tooth tap) varied, depending on the method, force and level of the muscle activity (1-19, 36-39). The interneurons in supratrigeminal nucleus are considered as inhibitory interneurons that mediate reflex inhibition of jaw-closing motor neurons from a variety of peripheral sources because they receive the converging afferent inflow from stimulation of different receptors. Tensile forces stretching the periodontal ligament stimulate afferent receptors in the ligament, which conduct to the interneurons and then to the motorneurons eliciting a single short duration silent period, regardless of the amount of the force generated between the opposing teeth. The only condition is that the force is perpendicular to the occlusal surface of the tooth, as it intrudes the teeth into the tooth socket along the long axes of the root of the tooth, thus stretching uniformly periodontal ligament. For this reason, a single silent period appeared in the electromyogram of the open-close--clench cycle.

Afferents from the other receptors, or even from the same periodontal receptors, but under altered conditions (if the force is not stretching periodontal ligament uniformly and if it is causing pressure to any part of periodontal ligament) could elicit prolonged silent periods, or double silent periods, as other authors noticed (1-19) . Brodin et al. (10) tapped the vestibular surfaces of frontal teeth with varying perpendicular forces and recorded prolonged, double or even triple silent periods, the duration being longer when the forces were more powerfull. This could be explained by the fact that the receptors in the periodontal ligament were not uniformly stretched, but some of them were pressed in the direction of the force. Thus, stretched ligament receptors could cause one short inhibition and pressed receptors could project to the nucleus supratrigeminalis through more synapses causing the second or third inhibition, or the inhibitory pauses could be fused into one inhibitory pause of long duration. However, vibration during more forceful teeth tapping, which might not be short and uniform, could also be responsible for stimulation of different receptors; i.e. different afferent inflow through the different number of synapses could be involved before projecting to the nucleus supratrigeminalis.

If the vibration is the most important factor eliciting silent period, then uniform contact of the opposing teeth also contribute to the short duration of the reflex, as in this study due to the uniform occlusal contact. Silent periods of longer duration, double inhibitory phases, etc., elicited after menton tapping (7, 9, 36-40), could be attributed to the longer vibration by the hammer menton tap, or by stimulating cutaneous receptors of the skin on the chin.

The bilateral nature of the reflex with regard to the latency and duration of the silent period is proved in this study as there was no significant difference between muscles and between left or right side muscles. These bilateral responses are in agreement with the results of other authors, who elicited the silent period during muscle contraction by mechanical stimulation of a tooth (periodontal mechanoreceptors) (10, 40-42) through light tooth tapping, regardless of weather they were bi- or unilaterally innervated teeth (42), although the authors agree (40-42) that such stimuli would also have excited receptors outside the periodontal ligament.

Mean voltages for the isotonic and isometric muscle activity for the examined muscles, as well as mean voltages during isometric maximum voluntary clenching are presented in Table 2.

No significant difference was registered between isotonic and isometric muscle activity in open-close--clench cycles for each muscle ($p>0.05$), or between muscles (Table 2, F test, post hoc Sheffe). Isotonic and isometric activity in the open-close-clench cycles were almost of the same values within the muscle. However, maximum voluntary clenching produced higher myoelectric activity than isotonic or isometric muscle activity in the open-close--clench cycle ($p<0.05$, F test, post hoc Sheffe, Table 2).

It is known that the level of previous muscle activity influences the duration of the silent period (11, 43, 44) and that a negative relation exists between the level of previous muscle activity and the silent period duration, although some authors state that the duration of the silent period is not changed by variation of clenching force (45, 64). The latest studies point out that the duration of inhibition depends on the firing rate of motoneurons, which fire at higher rates at higher occlusal forces, and with higher forces also new, higher amplitude and higher threshold motor units are included (14, 47).

In this study, isotonic activity varied between 60% to 70% of the maximum voluntary clenching activity during open-close-clench tasks. Variation in the muscle activity during open-close-clench tasks was not influenced by any explanation to the participants. The open-close-clench cycles were done spontaneously by each individual, who opened their mouth before the task in a way which was comfortable for them and then closed the mouth in the same way. Variation in muscle activity during spontaneous tasks was not greater than in participants who tried to maintain certain muscle activity through feedback methods during experiments. The silent period was elicited through different methods during the isometric clenching level varying between 10%, 25%, 40% to 100% of the maximum voluntary activity (7, 10, 11, 36-39).

Although silent periods in this study were elicited in open-close-clench cycles, with isotonic muscle activity being approximately 60-70% of the maximum voluntary clencing activity, the latencies and the duration of the short latency reflex response were not different from the silent periods elicited during 10, 25 or 40% of the maximum voluntary clencing activity (7, 10, 11, 36-39). In this study, long latency response was not noticed, as it was when the silent period had been elicited by other methods (chin tap, or forceful tooth tap in perpendicular direction to the long axis of periodontal ligament) (10, 36-39).

To check if the level of previous isotonic muscle activity is related to the duration of the registered single short latency and short inhibition silent period, correlation analysis was made between isotonic muscle activity and the silent period duration for each muscle. Coefficients of correlation were small and insignificant (right anterior temporalis, r=-0.09), (left anterior temporalis, r=0.019), (right masseter, r=0.02), (left masseter, r=0.001), which indicate the consistent spontaneous closing muscle activity during open-close-clench cycle, because possible changes in electrovoltage would have influenced the duration of silent period.

Conclusions

The values for the latency and duration of the silent period of jaw closing muscles in subjects with normal occlusion of the opposing teeth, elicited in open-close-clench cycles should be assumed as referent values for healthy individuals with normal occlusion. Reflex was fully symmetrical and of equal latency and duration between right and left temporal and right and left masseter muscles. Regardless of weather vibratory stimuli or forces stretching periodontal ligament receptors are responsible for the reflex, the reflex is an olygosinaptic one, because of its short latency and short duration. Mean isotonic voltages were equal to mean isometric voltages for each muscle in all open--close-clench cycles. Mean isotonic activity was spontaneously constant between open-close-clench cycles and was approximately 60% to 70% of the activity during maximum voluntary clencing.