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ORIGINAL ARTICLE

Effect of teeth clenching on handgrip force in adult men: role of periodontal mechanoreceptors

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Abstract

Purpose Voluntary teeth clenching is shown to increase the strength of muscle reflexes contributing to the improvement of postural stability. However, the interaction between the handgrip strength and teeth clenching is not yet understood. In this study, we aimed to evaluate the change in handgrip force in response to voluntary teeth clenching, and its relation to the peripheral receptors that play a central role in the control of mastication.

Methods Thirty-six healthy men were divided into two groups: aged 50–59 years, no dental prosthesis, and 53–62 years with total dental prosthesis. Each individual was given handgrip and teeth clenching instructions for five experiments: only handgrip, teeth clenching followed by handgrip without teeth clenching, teeth clenching followed by handgrip with teeth clenching, and the repetition of the last two instructions while wearing mouth guards.

Results Our findings showed that maximum handgrip force decreased and the resistance to fatigue increased in complete edentulous individuals using appropriate prostheses. Also, the significantly lower maximum handgrip force and higher resistance to fatigue values of the participants with dental prosthesis using a mouth guard while teeth clenching, revealed the central roles of periodontal mechanoreceptors.

Conclusion Decreases in masticatory sensory information processes influence handgrip force values which is the most important indicator of motor function. The lack of periodontal mechanoreceptors associated with dental prosthesis usage may lead to a loss in muscle strength.

Keywords Bite force · Masticatory receptors · Hand dynamometer · Handgrip strength · Mouth guard

Introduction

Handgrip strength is the result of forceful flexion of all finger joints with the maximum voluntary force that a subject can exert under normal bio kinetic conditions [1]. The level of handgrip force is regarded as the most reliable clinical measure of overall muscle strength [2, 3]. It is widely used in adults as an indication of strength in fitness testing, and as such is seen as the measurement most reasonably representative of total body strength [4, 5].

During the last decade the effect of oral health on general well-being has attracted growing interest [6]. The presence of incomplete teeth, gingival bleeding, and periodontitis caused by previous oral infections, have been reported to lead to decreases in muscle strength [7–9]. Many mechanisms help explain the relationship between oral health status and muscle strength. Signals from periodontal mechanoreceptors are shown to be used in the fine motor control of the jaw, and that important sensory-motor functions are lost or impaired when these receptors are removed during the extraction of teeth [10]. Masticatory receptors (periodontal mechanoreceptors, temporomandibular joint receptors, muscle spindles and oral mucosal receptors) signal information about tooth loads to the central nervous system and are considered to be important for the control of oral motor behaviors, like biting and chewing [11]. Dental occlusion influences the muscle tone of both masticatory and postural

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muscles involved in the preservation of balance. The lack of posterior bite support and malocclusion was reported to limit athletic performances. Furthermore, the mandibular position was suggested to affect head posture and consequently influence the muscular function in other parts of the body [12–15].

A common observation is that people usually clench their teeth unconsciously while trying to lift a heavy load suggesting a possible link between intraoral motor-sensory and total body strength. Voluntary teeth clenching is shown to increase the strength of muscle reflexes contributing to the improvement of postural stability [16]. However, the interaction between the handgrip strength and teeth clenching is not yet understood. In this study, we aimed to evaluate the change in handgrip force in response to teeth clenching, and its relation to the peripheral receptors that play central role in the control of mastication. To this end, we planned to apply five experimental conditions designed to understand the change in handgrip force versus activation of masticatory receptors (via teeth clenching) to both intact teeth (in the presence of periodontal mechanoreceptors) and complete denture wearer (without periodontal mechanoreceptors) individuals. Our hypothesis is that the muscle strength of individuals with complete dentures decreases and their resistance to fatigue increases (hypothesis 1). Another hypothetical approach is that those with intact teeth will increase their muscle strength and decrease their resistance to fatigue (hypothesis 2). In addition, if intraoral motor-sensory system activation contributes to the development of motor reflexes, the use of mouth guards that cause greater masticator receptor activation may increase upper extremity muscle strength and reduce resistance to fatigue (hypothesis 3).

Methods

Participants

This study was conducted in the Electrophysiology Laboratory of Department of Physiology at Hacettepe University, Faculty of Medicine. Thirty-six healthy men (age range 50–62 years) participated in this study. Since the volunteer subjects were recruited from the patients who applied to the clinic periodontology department, the oral examination of each subject was performed by the dentist, and the neurological anamnesis and examinations of the volunteers were performed by neurophysiologists (M.D.), who planned the experimental study. Based on the medical and dental history and oral examination, none of the subjects had disease or injury that might affect hand strength, neurological disorders or abnormalities in stomatognathic function, orofacial pain complaints, and extraordinary exercise and living habits, which may have a potential effect on the hand strength. As a result of the Diagnostic Criteria for Temporomandibular Disorders [17] algorithm applied to the volunteer participants, none of them was diagnosed with temporomandibular disorder ('The Diagnostic Criteria for Temporomandibular Disorders algorithm' is presented as additional sheets in Table 5 and Table 6). The dominant hand for writing and exercise was the right hand for all the subjects. The age, height and weight of subjects were recorded. Essential clinical and demographic characteristics of study participants in the two groups are listed in Table 1. Subjects of similar ages were equally divided into two groups according to their usage of dental prosthesis: aged 50–59 years, no prosthesis (the first was named "no denture"), and 53–62 years with dental prosthesis (the second was named "denture wearer"). "No denture" includes subjects with at least 28 ± 1.2 teeth in their mouths, and with normal periodontal examinations. The "denture wearer" included complete denture wearers, and participants with incomplete dentures were excluded. The prosthesis and tooth conditions in each denture wearer was clearly defined as: "Prostheses of edentulous subjects were removable complete dentures with bilaterally balanced occlusion."

Preparation for experiments and positioning

For measuring handgrip force, subjects were seated in a straight-backed dental chair with both feet and arm supported. Since the posture and elbow positioning during testing plays an important role in the strength results,

Table 1 Essential clinical and demographic characteristics of study subjects in two groups

	"No denture"	"Denture wearer"
Number of subjects	18	18
Gender distribution (male/female)	18/0	18/0
Age (years), *mean* ± *SD*	54.3 ± 1.2	58.3 ± 1.0
Dental prosthesis (complete denture wearers)	No	Yes
Duration of prosthesis (years), *mean* ± *SD*	–	10.2 ± 2.2
Body mass index (kg/m^2), *mean* ± *SD*	27.2 ± 0.7	26.1 ± 1.2
Smoking	0	4

SD standard deviation

positioning standardized by the American Society of Hand Therapists [18, 19] and Mathiowetz et al. was adopted to improve the reliability and validity of hand strength evaluations [20]. Accordingly, the subject sat on a chair with the shoulder adducted and neutrally rotated, the elbow flexed to 90-degrees, the forearm in a neutral position, and the wrist between 0- and 30-degrees extension. The hand dynamometer was presented vertically and in line with the forearm to maintain the standard forearm and wrist positions [18]. In this position, the elbow is the most stable and wrist extension allows greater mechanical advantage for flexor tendons resulting in maximum handgrip force [20, 21].

Measures

Handgrip force measurement

After positioning, maximum handgrip force of dominant hands was measured using an isometric hand dynamometer (Biopac Systems), which improves experiment repeatability and accuracy. The force applied to the hand dynamometer was amplified by the amplifier through low pass filter (< 100 Hz) and transmitted to the computer at a sample rate of 2 kHz. In addition to maximum handgrip force, fatigue resistance was also evaluated. Fatigue resistance, defined as maintaining one's maximal effort, is independent of the initially produced force. To assess the ability to sustain strength, the strength versus time curve was computed, and the time (s) during which handgrip force was reduced to 50% of maximum handgrip force was used as an indicator of fatigue resistance (Fig. 1a).

Teeth clenching force measurement

Teeth clenching force was assessed by electromyography (EMG) activity from the bilateral masseter muscles using bipolar surface EMG (sEMG) recording electrodes (DuoTrode) with 12.5 mm active surface and 19 mm spacing. By measuring the skin resistance of the bipolar electrodes with a voltmeter, it was ensured to be below 10kΩ and that the subjects were grounded with a 'lip-clip' [22]. The sEMG outputs were recorded to the computer at a sampling rate of 2 kHz after being amplified with a custom-made amplifier (band-pass filter, 20–500 Hz). The maximum voluntary force was obtained after three 5 s trials during which subjects were asked to clench their teeth as much as possible. The greatest maximum voluntary force was defined as 100% maximum voluntary force (Fig. 1b).

Mouth guards

Sterile individualized mouth guards (Selex) placed into the upper and lower jaws were used during two sets of experiment 4 and experiment 5. Mouth guards were standardized for each subject by preparing them as follows: (1) Mouth guards were made of silicone as used in contact sports. (2) Before each experiment in which mouth guards were used, they were placed in a container filled with water at a temperature of 26 degrees and kept for 3 min. (3) Silicone mouth guards were brought to a compatible consistency for both intact teeth and removable complete denture wearers. (4) Before giving the test commands regarding the experimental conditions in which mouth guards are used, silicone mouth guards of appropriate consistency were applied on the upper and lower teeth or dental prosthesis.

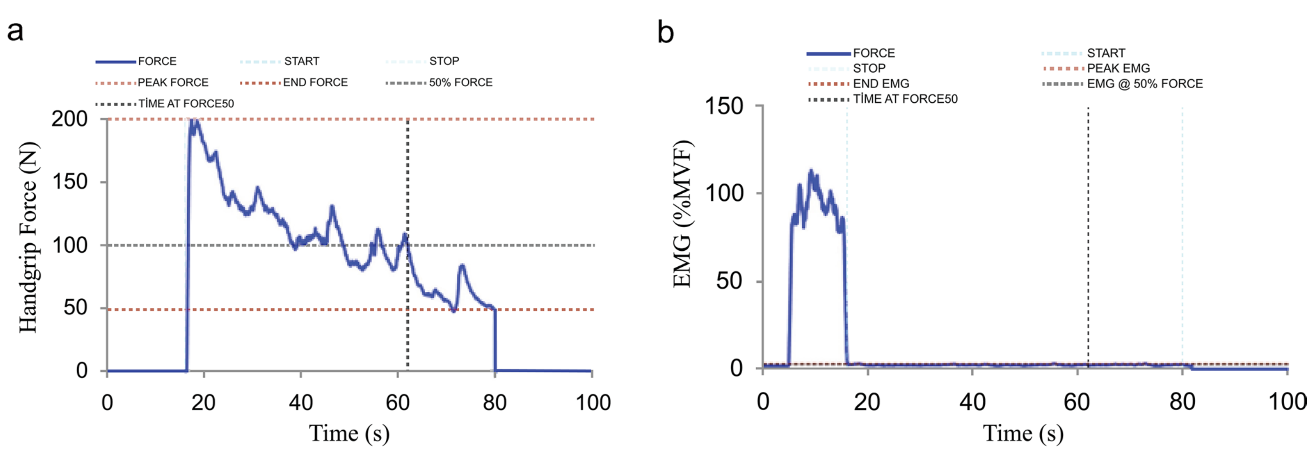

Fig. 1 (**a**) To assess the ability to sustain strength, force versus time curve is computed, and time (s) during which grip force is reduced to 50% of maximum handgrip force (N) is used as an indicator of fatigue resistance. (**b**) The graphic image above shows the electromyography (EMG), maximum voluntary force% (%MVF) recording from masseter muscle of the same subject who performs teeth clenching before handgrip. s: seconds, N: Newton

Contact status between lower and upper jaw

Status of contact between the mandible and maxilla (with or without the use of a mouth guard) was accepted as central occlusion a line with the vertical dimension (nose-jaw line) for both those with intact teeth and with removable complete denture wearers.

Experimental design

The tendency of people to teeth clenching when applying force was the main motivation for creating our experimental conditions. Thus, to reveal whether the masticatory receptors have an effect on motor force, the teeth clenching task was set at different time intervals (before, during and after the hand grip), and the 10 s (s) effect on the formed handgrip force was tried to be understood. Subjects were informed about the teeth clenching command in advance (10 s of voluntary teeth clenching). Special mouth guards were prepared for the subjects to activate the maximum number of masticatory receptors (periodontal mechanoreceptors, temporomandibular junction receptors, muscle spindles and oral mucosal receptors). We attempted to predict the possible effects of periodontal mechanoreceptors on motor control by including complete denture wearers, who are known to have abolished periodontal mechanoreceptors, in our experimental study. While designing the experimental conditions and the tasks of the subjects, special attention was paid to obtain maximum information from the oral sensory system. Thus, the effect of the oral sensory system on the upper motor system and the opportunity to compare both systems with each other were created.

Experimental protocol

Each individual was given handgrip and teeth clenching instructions for five experiments; squeezing the hand dynamometer with as much force as possible (experiment 1 ‘*Hand-grip’*), teeth clenching for 10 s followed by handgrip without teeth clenching (experiment 2 ‘*Teeth clenching → Hand-grip’*), teeth clenching for 10 s and handgrip as teeth clenching continues (experiment 3 ‘Teeth clenching → *Hand-grip + Teeth clenching’*), while wearing mouth guards teeth clenching for 10 s and then handgrip without teeth clenching (experiment 4 ‘*Mouth guard → Teeth clenching → Hand-grip’*), and while wearing mouth guards teeth clenching for 10 s and handgrip as teeth clenching continues (experiment 5 *‘Mouth guard → Teeth clenching → Hand-grip + Teeth clenching’*) (handgrip time is 65 s for “no denture” and “denture wearer” subjects) (Table 2). Five experiments were applied in a different random order for each subject who would rest for 20–25 min between experiments to avoid muscle fatigue.

Details of experimental instructions and training of participants

Before the experiments, the participants were trained and practiced handgrip and teeth clenching with maximum strength. They were instructed to keep their lower jaw in natural and relaxed position with the teeth apart except for the period of teeth clenching. They were also motivated during the experiment to apply their maximum strength and not to stop prematurely. A monitor was set in front of the subject at about 1 m, and he was asked to squeeze the hand dynamometer with as much force as possible when red line was displayed on the unit (Feedback on the level of voluntary clenching was specifically adjusted for each subject: In the feedback monitor, the subjects were asked to reach the '0' level white line to the target (red) line, 100% maximum voluntary force by biting). In the same monitor, a visual feedback was given on muscle activity during teeth clenching to obtain maximum clenching strength. The teeth clenching duration of the subjects (10 s) was counted audibly throughout the experiment, and when the time expired, the " leave teeth clenching " command was given by the researchers. No feedback regarding the performance was given during the measurements. The experiments were started either at 10.00 in the morning or at 14.00 in the afternoon and lasted 3–3.5 h per subject.

Recording and analysis of study parameters

For the recording, display and analysis of different physiological parameters (maximum voluntary force of right and left masseter muscles and handgrip force) at the same time,

Table 2 Description of five sets of experiments applied to all subjects

	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Mouth guard				+	+
Teeth clenching for 10 s		+	+	+	+
Handgrip without teeth clenching for 65 s	+	+		+	
Handgrip with teeth clenching for 65 s			+		+

s seconds

a computer equipped with a special card (LabVIEW), and a processing software (IZZY) was used.

Sample size calculation

Zhang N, Wang Q, Pan K. [The effect of mouthguard on strength of the musculus deltoideus]. Zhonghua Kou Qiang Yi Xue Za Zhi. 2001 and Tuncer M, Tucker KJ, Turker KS. Influence of tooth clench on the soleus H- reflex. Arch Oral Biol. 2007: In these two scientific studies similar to our study, research was conducted on $n=8$ and $n=9$ subjects, respectively. Considering these references, fatigue resistance (time (s) to 50% of maximum hand-grip force) values revealed in the pilot study ($n=12$) for experiment 1 '*Hand-grip*'; "no denture" ($n=6$, male, 54 ± 2.1 years): 40.1 s $\pm$ 4.2, "denture wearer" ($n=6$, male, 57 ± 2.1 years): 45.2 s $\pm$ 4.7. For 90% power, the effect size was $d=1.25$, $\alpha=0.05$, and the sample size was calculated with the statistical package program G*Power 3.1.9.7 (Franz Faul). Accordingly, it was understood that the minimum 30 ($n1=15$, $n2=15$) subjects was sufficient. A decision was made to increase the sample size by 20% ($n1=18$, $n2=18$) to compensate for possible exclusions from the study due to various reasons.

Statistical analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences software for Windows (SPSS version 25.0, IBM Corporation). Descriptive statistical methods (frequency, mean, standard deviation, median, min–max) were used while evaluating the study data. The conformity of the data to the normal distribution was evaluated with the Shapiro–Wilks test. The quantitative data of the study did not show a normal distribution. Mann–Whitney *U* test was used to compare differences between groups. The Friedman test was used to compare the five experimental conditions. Significance values have been adjusted by Bonferroni correction for multiple tests. All the analyses were conducted at a 95% confidence level. Statistically significant level was accepted as $P=0.05$. Power Analysis: (Experiment 1 '*Hand-grip*', 50% of maximum handgrip force values (s) are calculated). Power analysis was performed with the statistical package program *G**Power 3.1.9.7 (Franz Foul); $n_1=18$ (40.1 $\pm$ 4.3), $n_2=18$ (46.1 $\pm$ 4.4), $\alpha=0.05$, Effect size (d) = 1.37; power = 97%.

Results

Maximum handgrip force

The median values of the maximum handgrip force without teeth clenching and mouth guard (experiment 1 '*Hand-grip*') were 158.2 N, and 119.7 N, in "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P=0.001$) (Table 3, Fig. 2).

Table 3 The maximum handgrip force of study groups during five sets of experiments

Maximum handgrip force (N)	"no denture" ($n=18$)	"denture wearer" ($n=18$)	*P* value (between groups)*
Experiment 1 *Hand-grip*	158.2 (142.6–167.8)	119.7 (103.1–135.6)	0.001
Experiment 2 *Teeth clenching → Hand-grip*	156.4 (138.9–216.3)	155.7 (106.6–170.0)	0.01
Experiment 3 *Teeth clenching → Hand-grip + Teeth clenching*	172.4 (153.3–185.0)	139.9 (117.6–146.7)	< 0.001
Experiment 4 *Mouth guard → Teeth clenching → Hand-grip*	174.8 (165.5–201.2)	136.5 (124.2–165.3)	< 0.001
Experiment 5 *Mouth guard → Teeth clenching → Hand-grip + Teeth clenching*	176.4 (161.4–200.1)	127.2 (117.7–144.3)	< 0.001
P value (Between experiments)**	< 0.001	0.001	
Difference ***	Experiment 1–2 and 3–4-5	Experiment 2 and 1–5	

N Newton. *Mann–Whitey *U* test. ** Friedman Test. *** Bonferroni correction for multiple tests

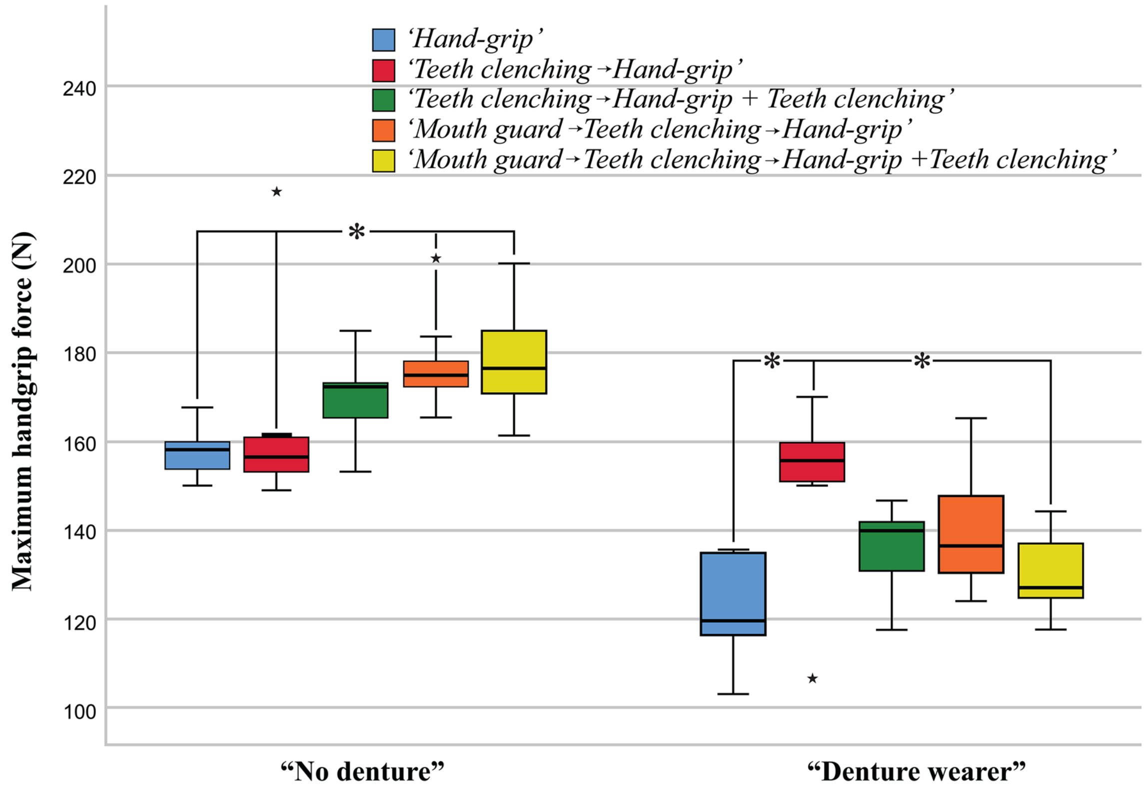

Fig. 2 The maximum handgrip force (N) of study groups during five sets of experiments, N: Newton. The median values of the maximum handgrip force: experiment 1 '*Hand-grip*' were 158.2 N, and 119.7 N, in "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P=0.001$); relationship between handgrip force and teeth clenching (experiment 2, 3, 4 and 5) experiment 2 '*Teeth clenching→Hand-grip*' were 156.4 N, and 155.7 N (P=0.01), experiment 3 '*Teeth clenching→Hand-grip+Teeth clenching*' 172.4 N and 139.9 N; experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' 174.8 N and 136.5 N and in experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' 176.4 N and 127.2 N, "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P<0.001$); relationship between the experimental conditions were found statistically significant among the groups ("no denture") experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' (174.8 N) and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' (176.4 N) were significantly higher than experiment 1 '*Hand-grip*' (158.2 N) and experiment 2 '*Teeth clenching→Hand-grip*' (156.4 N) ($P<0.001$). In this group, it was revealed that participants who used mouth guards had higher maximum handgrip force ($P<0.001$). ("denture wearer") experiment 1 '*Hand-grip*' (119.7 N) and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' (127.2 N) were significantly lower than experiment 2 '*Teeth clenching→Hand-grip*' (155.7 N) ($P=0.001$)

Relationship between handgrip force and teeth clenching (experiment 2, 3, 4 and 5): The median values of maximum handgrip force in experiment 2 '*Teeth clenching→Hand-grip*' were 156.4 N, and 155.7 N, in "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P=0.01$). The median values of maximum handgrip force were in experiment 3 '*Teeth clenching→Hand-grip+Teeth clenching*' 172.4 N and 139.9 N; in experiment 4 '*Mouth guard→Teeth clenching→Hand*-grip' 174.8 N and 136.5 N and in experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' 176.4 N and 127.2 N, "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P<0.001$) (Table 3). These findings revealed that the maximum handgrip force values of the participants with dental prosthesis especially using a mouth guard while teeth clenching were the significantly lower.

Relationship between maximum handgrip force values and the experimental conditions were found to be statistically significant among the groups; ("no denture") experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' (174.8 N) and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' (176.4 N) were significantly higher than experiment 1 '*Hand-grip*' (158.2 N) and experiment 2 '*Teeth clenching→Hand-grip*' (156.4 N) ($P<0.001$). In this group, it was participants who used mouth guards had higher maximum handgrip force ($P<0.001$); ("denture wearer") experiment 1 '*Hand-grip*' (119.7 N) and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' (127.2 N) were significantly lower than experiment 2 ‘*Teeth clenching → Hand-grip*’ (155.7 N) ($P = 0.001$). These findings revealed that there is a relationship between teeth clenching and maximum handgrip force in the group using dental prosthesis (Table 3 and Fig. 2).

Fatigue resistance

As an indicator of fatigue resistance, time (s) during which maximum grip strength was reduced to 50% of the median values of maximum handgrip force was compared between study groups and experiments.

Without teeth clenching and mouth guard (experiment 1 ‘*Hand-grip*’): The median values of fatigue resistance (s) were 40.2 s, and 46.6 s, in “no denture”, “denture wearer” respectively; being significantly highest in “denture wearer” ($P = 0.002$, Table 4 and Fig. 3).

Relationship between fatigue resistance and teeth clenching (experiment 2, 3, 4 and 5): The median values of fatigue resistance were in experiment 2 ‘*Teeth clenching → Hand-grip*’ 40.6 s and 53.8 s ($P = 0.002$); in experiment 3 ‘*Teeth clenching → Hand-grip + Teeth clenching*’ 51.0 s and 55.0 s ($P < 0.001$); in experiment 4 ‘*Mouth guard → Teeth clenching → Hand-grip*’ 42.6 s and 48.8 s ($P = 0.031$) and in experiment 5 ‘*Mouth guard → Teeth clenching → Hand-grip + Teeth clenching*’ 47.6 s and 59.4 s ($P = 0.009$) in “no denture”, “denture wearer” respectively; being significantly highest in “denture wearer” ($P < 0.001$). These findings revealed that the fatigue resistance values of the participants with dental prosthesis while teeth clenching especially continues were the significantly higher (Table 4).

Relationship between fatigue resistance values between the experimental conditions were found to be statistically significant among the groups; (“no denture”) experiment 3 ‘*Teeth clenching → Hand-grip + Teeth clenching*’ (51.0 s) was found to be significantly higher than experiment 1 ‘*Hand-grip*’ (40.2 s), experiment 2 ‘*Teeth clenching → Hand-grip*’ (40.6 s) and experiment 4 ‘*Mouth guard → Teeth clenching → Hand-grip*’ (42.6 s) was found to be significantly higher than experiment 1 ‘*Hand-grip*’ (40.2 s) ($P < 0.001$); (“denture wearer”) experiment 3 ‘*Teeth clenching → Hand-grip + Teeth clenching*’ (55.0 s) and experiment 5 ‘*Mouth guard → Teeth clenching → Hand-grip + Teeth clenching*’ (59.4 s) were found to be significantly higher than experiment 1 ‘*Hand-grip*’ (46.6 s) ($P = 0.002$). These results revealed that there is a relationship between teeth clenching and the ability to sustain strength in the group using dental prosthesis. The fatigue resistance values of the participants with dental prosthesis while teeth clenching especially continues were the significantly higher (Table 4, Fig. 3).

Discussion

In the present study, we evaluated the change in handgrip force in response to teeth clenching. In addition, we investigated the effects on muscle fatigue and the possible

Table 4 As an indicator of the fatigue resistance, time (s) during which handgrip force was reduced to 50% of maximum handgrip force in study groups

Fatigue resistance (time to 50% of maximum handgrip force (s))	“no denture” ($n = 18$)	“denture wearer” ($n = 18$)	P value (between groups)*
Experiment 1 *Hand-grip*	40.2 (32.4–45.2)	46.6 (41.9–49.8)	0.046
Experiment 2 *Teeth clenching → Hand-grip*	40.6 (34.7–46.7)	53.8 (47.9–55.3)	0.002
Experiment 3 *Teeth clenching → Hand-grip + teeth clenching*	51.0 (48.5–56,5)	55.0 (48.1–61.3)	< 0.001
Experiment 4 *Mouth guard → Teeth clenching → Hand-grip*	42.6 (36.9–46.4)	48.8 (30.5–62.2)	0.031
Experiment 5 *Mouth guard → Teeth clenching → Hand-grip + teeth clenching*	47.5 (41.9–53.1)	59.4 (52.4–62.3)	0.009
P value (Between experiments)**	< 0.001	0.002	
Difference ***	Experiment 3 and 1–2–4	Experiment 1 and 3–5	

s seconds. * Mann–Whitey U test. ** Friedman Test ***Bonferroni correction for multiple tests

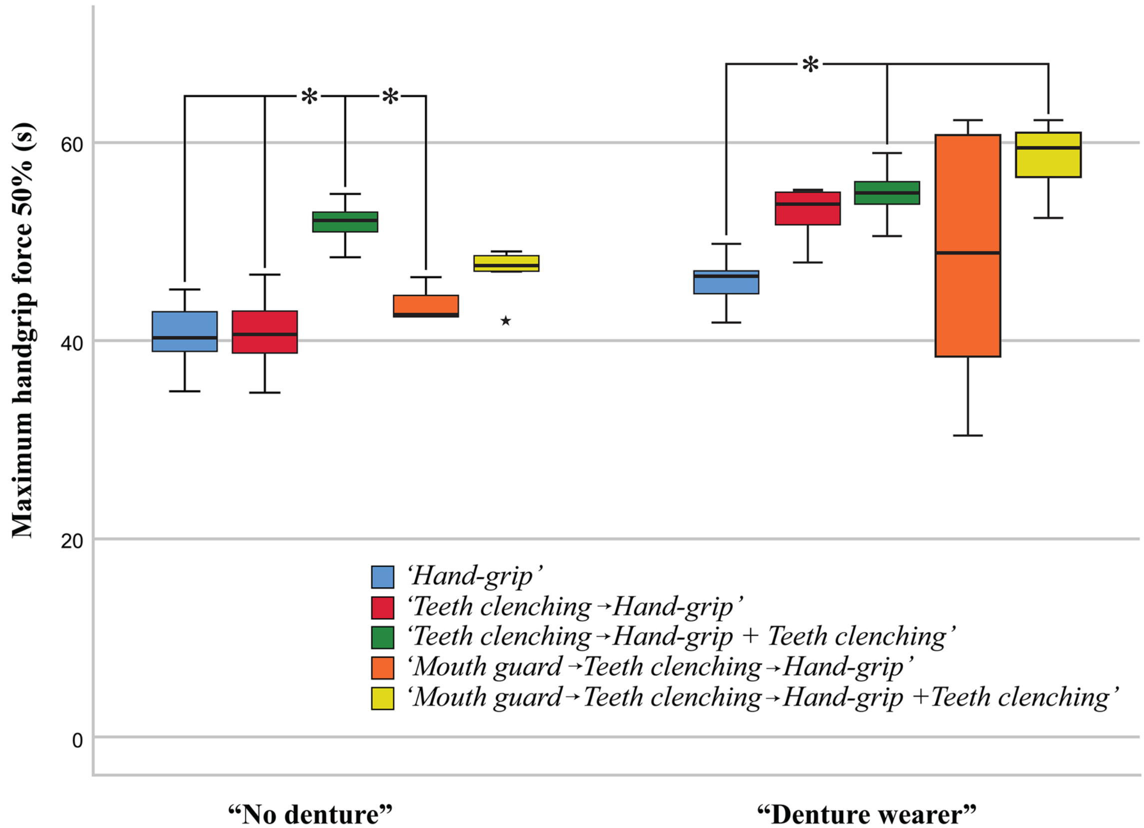

Fig. 3 As an indicator of the fatigue resistance, time (s) during which handgrip force was reduced to 50% of the maximum handgrip force in study groups. s, seconds. The median values of fatigue resistance (s): experiment 1 '*Hand-grip*' were 40.2 s, and 46.6 s, in "no denture", "denture wearer" respectively; being significantly highest in "denture wearer" ($P=0.002$); relationship between fatigue resistance and teeth clenching (experiment 2, 3, 4 and 5): experiment 2 '*Teeth clenching→Hand-grip*' 40.6 s and 53.8 s ($P=0.002$); in experiment 3 '*Teeth clenching→Hand-grip+Teeth clenching*' 51.0 s and 55.0 s ($P<0.001$); in experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' 42.6 s and 48.8 s ($P=0.031$) and in experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' 47.6 s and 59.4 s ($P=0.009$) in "no denture", "denture wearer" respectively; being significantly lowest in "denture wearer" ($P<0.001$); relationship between the experimental conditions were found statistically significant among the groups: "No denture"; experiment 3 '*Teeth clenching→Hand-grip+Teeth clenching*' 51.0 s was found to be significantly higher than experiment 1 '*Hand-grip*' 40.2 s, experiment 2 '*Teeth clenching→Hand-grip*' 40.6 s and experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' 42.6 s ($P<0,001$), "Denture wearer"; experiment 3 '*Teeth clenching→Hand-grip+Teeth clenching*' 55.0 s and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*' 59.4 s were found to be significantly higher than experiment 1 '*Hand-grip*' 46.6 s ($P=0.002$)

connections of such effects with masticatory receptors. The possible effects of periodontal mechanoreceptors were evaluated with subjects wearing complete dentures ("denture wearer") and those with intact teeth ("no denture"). Moreover, the possible effects of other masticatory receptors were evaluated in experimental conditions in which subjects wore mouth guards (experiment 4 '*Mouth guard→Teeth clenching→Hand-grip*' and experiment 5 '*Mouth guard→Teeth clenching→Hand-grip+Teeth clenching*'). Based on our results, teeth clenching caused an increase in the handgrip force. Although the primary role of this neurophysiological event seems to be related to periodontal mechanoreceptors, other masticatory receptors are also effective in motor control. This experimental study supports all three hypotheses.

The handgrip force can be influenced by many factors, including fatigue, hand dominance, time of day, age, nutritional status, pain, cooperation of the patient and presence of amputations, restricted motion, pain, and sensory loss [1, 4, 23]. To minimize the effects of environmental factors on handgrip force, we ensured that the study population was homogenous by having similar age distribution between study groups and including only male subjects. We performed all the measurements at the same time of the day and positioned the subjects according to positioning standardized by the American Society of Hand Therapists [18].

One of the remarkable findings of the present study was a decreased maximum handgrip force in subjects using a dental prosthesis (hypothesis 1). In the complete or partially edentulous patients, wearing an appropriate prosthesis is important for the restoration of masticatory function and additionally for the reconstruction of occlusal support to stabilize mandibular position during physical exercise [24]. Since periodontal mechanoreceptors are located on the intact teeth, the patients with dental prosthesis lack periodontal mechanoreceptors [10]. The periodontal mechanoreceptors signal information about forces applied to the teeth playing a role in the reflex control of human masticatory system and are located in the periodontal ligament, which attaches the root of the tooth to the alveolar bone [10, 11, 25, 26]. We suggest that the lack of periodontal mechanoreceptors is associated with impaired sensory and motor functions of teeth and lead to loss in muscle strength, increasing the risk of disability, particularly in elderly population.

When we encounter situations that require muscle strength, we clench our teeth as we exert force without realizing it. This has been experienced by many individuals as they try to lift a heavy weight [27–30]. During the physical effort, there is contraction within the masticatory musculature. This, in general, leads the subjects to compress the mandible against the maxilla. This action is often performed by exercise practitioners and athletes, more specifically during high-intensity physical efforts such as training or competition. Therefore, an athlete would withdraw from the sport due to trauma, caused by fractures and dental cracks [31]. Voluntary teeth clenching has been shown to increase the strength of muscle reflexes, and hence stronger reflexes are suggested to contribute to a more balanced stance [17, 32]. This study has revealed that voluntary teeth clenching leads to changes in the strength of the handgrip: (The present findings support the first hypothesis; 'the muscle strength of individuals with complete dentures decreases and their resistance to fatigue increases'); in the experiment 3 *'Teeth clenching → Hand-grip + Teeth clenching'* and experiment 5 *'Mouth guard → Teeth clenching → Hand-grip + Teeth clenching'* experimental conditions, where voluntary teeth clenching and handgrip instructions were given together, and also in experiment 4 '*Mouth guard → Teeth clenching → Hand-grip'*, handgrip force values in the subjects wearing dental prosthesis users ("denture wearer") were found to be significantly lower than the subjects not using a dental prosthesis ("no denture"). Relationship between fatigue resistance and teeth clenching (experiment 2, 3, 4 and 5) findings revealed that the fatigue resistance values of the participants with dental prosthesis while teeth clenching especially continues were the significantly higher. (The present findings support the hypothesis 2, 3); it was observed that in "no denture" including the participants with intact teeth (experiment 2 '*Teeth clenching → Hand-grip'*, experiment 3 *'Teeth clenching → Hand-grip + Teeth clenching'*) the handgrip force values were high in the experimental conditions in which mouth guards were worn (experiment 4 '*Mouth guard → Teeth clenching → Hand-grip'* and experiment 5 *'Mouth guard → Teeth clenching → Hand-grip + Teeth clenching'*). The findings of the relationship between fatigue resistance and teeth clenching (experiment 2, 3, 4 and 5) revealed that the fatigue resistance values of the participants with dental prosthesis compared with intact teeth while teeth clenching especially continues were the significantly higher. In this study, the handgrip force was shown to decrease in subjects not having periodontal mechanoreceptors, that is, those who wear dental prostheses ("denture wearer"), and that when mouth guards are used in participants with intact teeth ("no denture"), the handgrip force increases possibly due to the activation of other masticatory receptors. Our results support studies claiming that masticatory receptors, and in particular periodontal mechanoreceptors, play a central role in the motor control of teeth clenching and handgrip.

As long as natural teeth are present, periodontal mechanoreceptors function normally; they cannot continue this function when there are prosthesis or dental implants. Because, with the elimination of periodontal ligaments, periodontal mechanoreceptors are not able to convey the information about the mechanical events [25, 33]. In our study, more significant in the experimental conditions (experiment 3 *'Teeth clenching → Hand-grip + Teeth clenching'* and experiment 5 *'Mouth guard → Teeth clenching → Hand-grip + Teeth clenching'*) where the teeth clenching process continues until the end of the experiment, and in another experiment 4 '*Mouth guard → Teeth clenching → Hand-grip'* condition in which a mouth guard is used; maximum handgrip force values were higher in subjects not having total prosthesis in their mouth compared to those having prosthesis (the lack of periodontal mechanoreceptors). These findings demonstrate the relationship between the masticatory receptors-especially periodontal mechanoreceptor and intraoral sensory information and motor control during voluntary teeth clenching. The fatigue resistance values of all two groups were compared to evaluate the resistance to muscle fatigue. And the values were significantly higher for the subjects in the group using dental prosthesis. We think that making the effort to generate force (experiment 3 *'Teeth clenching → Hand-grip + Teeth clenching'* and experiment 5 *'Mouth guard → Teeth clenching → Hand-grip + Teeth clenching'*) while activating masticatory receptors with teeth clenching resulted in more strength and earlier fatigue demonstrating that handgrip force is inversely proportional with resistance to fatigue (the present findings support the all hypothesis). For the group without prosthesis, when mouth guard was used and teeth clenching was continued during handgrip (experiment 5 *'Mouth guard → Teeth clenching → Hand-grip + Teeth clenching'*) fatigue was experienced later especially when compared to experiment 1 '*Hand-grip*' and experiment 4 '*Mouth guard → Teeth clenching → Hand-grip'* (Contrary to hypothesis third). This helped us to strongly support the notion that periodontal mechanoreceptors played a central role among masticatory receptors. Our interpretation was that if other teeth are deprived of periodontal mechanoreceptors, despite stimulating with mouth guard (thanks to their silicon content, they adhere to the upper and lower jaw gingiva and mucosal tissues) other masticatory peripheral receptors (temporomandibular junction receptors, muscle spindles, oral mucosal receptors), muscle strength increases however fatigue is not experienced in a short period of time.

This study found that the output of handgrip dynamometry reveals more than an individual's handgrip strength. From nutritional status to physical functioning, this method of assessment can provide the practitioner with a cost-effective, non-invasive screening tool to evaluate patient's well-being [2]. Handgrip force, an indicator of overall muscle strength, may predict mortality through mechanisms other than those caused by disease to muscle impairment. Grip strength tests may help identify patients at increased risk of deterioration of health [34].

Maximum voluntary force obtained by teeth clenching is determined by neural drive from motor cortex to muscles in addition to muscle mass maximum voluntary force is thus an indicator of the functioning of both the neural and muscular systems [35, 36]. In a study using functional magnetic resonance imaging, Iida et al., detected activation only in the bilateral sensorimotor cortex during bilateral fist-clenching, while teeth clenching activated the bilateral sensorimotor cortex, supplementary motor area, dorsolateral prefrontal cortex, and posterior parietal cortex [37]. Since teeth clenching activated a more extensive cortical network compared to fist-clenching, they suggested that the teeth clenching may induce a more complex cerebral activity compared with the performance of a hand motor task.

Wearing a mouth guard and teeth clenching with maximum voluntary force may increase masseter muscle strength and reflectively improve deltoid muscle strength [38]. The mouth guards used in this study provided maximum voluntary force by causing full and balanced closures of the jaws (central occlusion suitable for the vertical dimension (nose-jaw line)). Using mouth guards, we investigated the possible effects of peripheral receptors of mastication other than periodontal mechanoreceptors (e.g. temporomandibular junction receptors, muscle spindles) on the maximum handgrip strength. Participants without dental prostheses using a mouth guard while teeth clenching had significantly higher maximum handgrip force, suggesting that the activation of temporomandibular junction receptors and muscle spindles may improve handgrip strength. The exact role of temporomandibular junction receptors and muscle spindles during teeth clenching and handgrip strength remains to be delineated. The significantly lower handgrip force values of the participants with dental prosthesis using mouth guard while teeth clenching revealed the central role of periodontal mechanoreceptors. Thus, we realized that without periodontal mechanoreceptors, teeth clenching would not have strong effects on motor force even if all masticatory receptors were activated (The present findings support the hypothesis third).

The main limitation of our study was its small sample size, which precludes us from reaching a definitive conclusion on the effect of teeth clenching on handgrip strength and role of peripheral receptors of mastication in this process. However, our findings are important in that it suggests that oral health and teeth clenching may be related to handgrip strength, which is an indicator of the general health status of the individual. Further studies with larger sample sizes are needed to clarify this relation and underlying neurological mechanisms.

In conclusion, our findings indicate that decreases in masticatory sensory information processes, influence handgrip force value as the most important indicator of motor function. This study demonstrates that masticatory receptors are activated by voluntary teeth clenching throughout the process of force exertion supporting the studies claiming periodontal mechanoreceptors play a central role in the motor control of teeth clenching and handgrip. The lack of periodontal mechanoreceptors associated with dental prosthesis usage leads to a loss in muscle strength. Therefore, both advancing age and deterioration of oral health have negative impact on body muscle strength. Since oral health is closely associated with the overall well-being of individuals, oral pathologies should be diagnosed earlier and treated effectively for a healthier movement system.

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Author contributions MK & MT all made substantial contributions to the conception and design of the study. MK & MT were responsible and involved in data collection. MK & MT were all involved in data interpretation, statistical analyses, drafting, and critically revising the manuscript. All authors have given final approval for the version to be published.

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Data availability The datasets analyzed during the current study are not publicly available due to the policy of the project agreement but are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflicts of interest.

Ethics approval and consent to participate and consent for publication Informed consent was obtained from all the participants included in the study. The study was approved by the Local Ethics Committee of Hacettepe University Faculty of Medicine (FON 08/31–31, 28 August 2008) and was conducted in accordance with the latest version of the Helsinki Declaration.

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