applied sciences

MDPI

Article

Maximal Bite Force Measured via Digital Bite Force Transducer in Subjects with or without Dental Implants—A Pilot Study

Shifra Levartovsky [1,*,†], Gitit Peleg [2,†], Shlomo Matalon [1], Igor Tsesis [3] and Eyal Rosen [3]

[1] Department of Oral Rehabilitation, The Maurice and Gabriela Goldschleger School of Dental Medicine, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv 6997801, Israel; matalons@tauex.tau.ac.il
[2] In Partial Fulfilment of a Graduate Program in Oral Rehabilitation, The Maurice and Gabriela Goldschleger, Sackler Faculty of Medicine, School of Dental Medicine, Tel Aviv University, Tel Aviv 6997801, Israel; drgititpeleg@gmail.com
[3] Department of Endodontics, Sackler Faculty of Medicine, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv 6997801, Israel; dr.tsesis@gmail.com (I.T.); dr.eyalrosen@gmail.com (E.R.)
* Correspondence: shifra@tauex.tau.ac.il
† These authors contributed equally to this article.

Abstract: The aims of the current study were as following: (1) to evaluate the maximal bite forces in patients with dental implants versus patients without dental implants, as measured by a digital bite force transducer (GM10); (2) to evaluate the influences of sex, age, and sleep/awake bruxism on the maximal bite forces of the two groups. Forty patients recruited to the study were divided into two groups: test group ("implant") if they had one or more posterior restored implants and control group ("no-implant") without the presence of posterior dental implants. A digital bite fork (GM10) was used to measure the bite forces from three posterior occluding pairs in all participants. Differences in the mean values between the test and control groups and between different sexes were evaluated using one-way and two-way ANOVA tests. A cross-tabulation analysis was conducted to identify a trend line between the groups. There was no significant difference in the maximal bite force between the test and control groups ($p = 0.422$), but the cross-tabulation analysis revealed a clear trend of a stronger representation of the "no-implant" group at higher occlusal forces. A significant difference was detected between the maximal biting forces of male and female subjects ($p = 0.030$ in the implant group, $p = 0.010$ in the no-implant group), regardless of the experimental group. The presence of bruxism and clenching did not influence the bite force values ($p = 0.953$), and a significant difference was not found between the age groups ($p = 0.393$). Within the limitations of this study, it may be assumed that there was no significant difference between the maximal bite forces between patients with and without dental implants but that there was a trend line implicating a stronger representation of the "no-implant" group at higher forces. In addition, the results revealed a significant sex-related difference in the maximal occlusal force. Further studies with larger sample sizes are warranted.

Keywords: maximal bite force; bite fork; tooth; dental implant

Citation: Levartovsky, S.; Peleg, G.; Matalon, S.; Tsesis, I.; Rosen, E. Maximal Bite Force Measured via Digital Bite Force Transducer in Subjects with or without Dental Implants—A Pilot Study. *Appl. Sci.* **2022**, *12*, 1544. https://doi.org/10.3390/app12031544

Academic Editor: Gabriele Cervino

Received: 4 December 2021
Accepted: 29 January 2022
Published: 31 January 2022

1. Introduction

Bite force results from the action of the jaw elevator muscles, as modified by jaw biomechanics and reflex mechanisms, and may vary widely in magnitude and direction [1]. The determination of bite force is considered an important parameter in assessing the function and efficacy of dental prostheses and orthodontic treatments and in studying the effect of deformities and pathologies, such as malocclusion and over loading, on the masticatory system [2].

During mastication, loading forces are created by masticatory muscles. The mechanoreceptors of the periodontal ligament control these muscles, and reduced periodontal support may influence their threshold level [3].

The accurate evaluation of a clinical diagnosis of periradicular (PR) conditions or the inflammation of the periodontal ligament around teeth requires a quantifiable method to measure the mechanical pain threshold. A reduction in "mechanical allodynia" (pain response to mechanical stimulus) evinces a high sensitivity for detecting PR pain as compared to pulpal pain [4,5]. The differences between the sensation or pain of a toothed patient and that of an edentulous patient can be due to the lack of the periodontal ligament.

When osseointegrated implants were introduced, it was believed that implants would be more susceptible to occlusal overloading due to the lack of a periodontal ligament and its proprioceptive capabilities [6]. These concerns have led to concepts of occlusion on implants, some of which persist today, although no scientific evidence exists regarding the preferred occlusal scheme that will minimize or eliminate complications [6]. In contrast, researchers showed that implant failure has been mainly attributed to peri-implantitis. This biological complication of oral implants is attributed to periodontal pathogens that cause the sub-acute and chronic inflammation of hard and soft tissues surrounding the implants. Therefore, the long-term prognosis depends on the amount of different microorganisms embedded in the biofilm matrix around implants [7]

Researchers showed that although peri-implant surroundings lack periodontal ligament receptors, there are no differences in the accuracy detection between loads applied to implants and loads applied to natural teeth [8]. Mühlbradt et al. studied the suprathreshold discrimination sensitivity of teeth and endosseous implants and found that loads applied to implants and to natural teeth were detected with the same accuracy in both cases [8]. This study and others have concluded that remote mechanoreceptors, that is, receptors which are located apart from of immediate tooth surroundings, might be responsible for the suprathreshold sensitivity of implants and natural teeth [9–13].

Mechanical pain thresholds in PR tissues can be measured by quantifying the amount of masticatory force that elicits pain. Khan et al. [14] conducted a study in which a digital bite force transducer—bite fork (Occlusal Force-Meter, GM10, Nagaro Keiki, Tokyo, Japan)—was placed between posterior teeth of normal healthy control subjects who had to bite on the transducer until they felt pain or discomfort. Because this study recruited subjects with normal PR tissues, the maximal biting force measured represents the normal mechanical pain threshold. The authors concluded that the bite fork has the potential as a quantitative diagnostic aid for measuring mechanical allodynia in patients with natural teeth and implants [14,15]. Since the maximum bite force is an objective measure of oral function and was demonstrated to be a key determinant of masticatory performance, we used this indicator for evaluating the difference between these two groups of patients [16,17].

The dental status of an individual might be expected to influence the bite, and fully dentate individuals could be expected to exhibit higher bite force values than individuals with complete dentures, removable partial dentures, or fixed partial dentures [16]. Nowadays, implant-supported rehabilitation has become common practice for tooth replacement due to trauma, dental caries, periodontal disease, or congenitally missing teeth. Interestingly, implant-supported overdentures were found to exert higher levels of the bite force than either root-retained overdentures or complete dentures [17]. In the course of dental implant treatment, occlusal overload can be one of the causes for implant failure [18–20]. Thus, a modified occlusal concept is recommended for implant-supported restorations, with a narrow occlusal table, a slight occlusal contact in the maximum intercuspation, and reduced occlusal forces during lateral movements [21,22].

Unfortunately, minimizing occlusal forces over implant-supported restorations may produce an overload on adjacent teeth. Lee et al. [23] showed that for splinted implants, traumatic occlusion in adjacent premolars was significantly higher, especially when maxillary teeth were measured with implants present in the opposing teeth. In addition, a number of other researchers reported a possible negative effect between implant-supported restorations and vertical root fractures (VRFs) or cracks in adjacent endodontically treated teeth [24,25]. A case series analysis revealed that the majority of the adjacent teeth with VRFs were premolar or mandibular molar teeth and that all fractured teeth were restored with a crown and had a post present [24]. Duqum et al. [26] demonstrated that the requirement for restorative retreatment was significantly higher for teeth adjacent to implant restorations than for the contralateral controls. Similarly, the results of a retrospective study conducted by Yoshino et al. [27] revealed that the percentage of the loss of teeth adjacent to implant-supported restorations was higher than that of other posterior teeth.

However, the question as to whether the bite force applied on teeth and implants in patients with dental implants is different to that in patients without dental implants remains unanswered. A precise clinical characterization of the biting force on teeth and implants will enable the treatment plan to be customized, with respect to choices of dental materials, occlusal scheme, contact points, and predictions of biting forces. To the best of our knowledge, there is very little information about this issue. Therefore, the aims of the current study are as following: (1) to evaluate the maximal bite force in patients with dental implants versus patients without dental implants, as measured by a digital bite force transducer (GM10); (2) to evaluate the influence of sex, age, and sleep/awake bruxsim on the maximal bite forces of the two groups. The null hypotheses are as follows: (1) no difference in the bite force applied to patients with or without dental implants was observed; (2) the maximal bite forces of the two groups were not affected by sex, age, and sleep/awake bruxism.

2. Materials and Methods

2.1. Sample

Prior to data collection, the approval was obtained from the Tel-Aviv University Institutional Ethical Committee (# 08410844_20180821). Written and oral informed consent was provided by all the participants.

Patients visiting the university dental clinic were enrolled in this study. Clinical factors (sex, age, implant quantity, and bruxism) were collected in order to characterize the relationship between the presence of implants and the bite force on teeth. Signs and symptoms for sleep/awake bruxism, according to the international consensus published by Lobbezoo et al. [28] and according to the signs and symptoms of bruxism published by the International Classification of Sleep Disorders [29], were recorded for each patient at the time of arrival, if present. In addition, an intraoral physical examination was conducted followed by the measurement of the bite force by the same examiner (G.P). Periapical radiographs were taken as part of the dental examination and were assessed by the same examiner (G.P). All subjects fulfilled the following inclusion criteria: (1) age over 20 years; (2) fixed rehabilitated posterior single dental implant or multiple splinted implants in the sites of premolars or molars with a minimum one-year placement time; (3) only patients with skeletal and dental class I; (4) natural teeth with healthy PR tissue or teeth with root canal and fixed prosthodontics (healthy PR tissue). The following exclusion criteria were applied: (1) systemic disease that might affect participants' neuromuscular systems (such as Parkinson's disease) at the time of assessment; (2) oral and orofacial complaints, temporomandibular disorders (TMDs), pain, or discomfort at the time of assessment; (3) patients with reduced periodontium; (4) teeth with pathologic PR tissue, active caries lesion, fracture, or with root canal treatment but without fixed prosthodontics; (5) opposing occlusion with full or partial removable denture prosthetics; (6) implants with biological and mechanical complications; (7) implants with occluding implants.

The participants were assigned to the test group ("implant") if they had one or more posterior restored implants with occluding natural teeth and to the control group ("no implants") if they had natural or restored dentition without the presence of dental implants in the mouth. The mechanical pain threshold (maximal bite force) was measured in vivo, in the posterior hemi arch with dental implants (test group) and was compared to the bite force in the corresponding posterior hemi arch without dental implants (control group). Each patient was tested in one or two posterior hemi arches; three occluding pairs were tested on each side. In cases when two posterior hemi arches of the same patient met the inclusion criteria, the experiments were repeated on both sides at the same appointment, and the results were documented as two separate observations.

2.2. Bite Force Measurements

The bite force was measured with a bite fork device (Occlusal Force-Meter, GM10, Nagaro Keiki, Tokyo, Japan), which comprised a hydraulic pressure gauge (Figure 1).

Figure 1. Occlusal Force-Meter, GM10.

The top surface of the device was covered with a diaphragm, and the pressure of liquid charged in the housing was measured with a built-in nanometer. A biting element, made of a vinyl material, was encased in a polyethylene tube termed the "disposable occlusal cap". The bite fork specifications were as following: force range, 0–1000 N; accuracy, ±1 N; and the dimensions, 17 mm in width, 5.4 mm in height, and 63.5 mm in length. Several in vivo studies have successfully used this device for recording bite force [30–38]. The subjects did not experience any discomfort or pain while biting on the instrument [16,17]. In addition, previous research showed that this specific bite fork has substantial test-retest reliability and is suitable for substantial inter-rater reliability [35].

The bite fork in the current study was modified by using an adhesive to attach the head of a rigid Tooth Slooth (Professional Results, Inc., Laguna Niguel, CA) to the fork, according to the modification described in the study of Khan et al. (Figure 2) [14].

Figure 2. The modification of the head of the Occlusal Force-Meter.

This modification acted as an occlusal guide and fulfilled two main purposes as following: to coordinate the forces in a vertical direction in order to prevent fractures and to raise the height of the fork to obtain an interocclusion height of 18 mm. It was shown that the maximum masseter bite force magnitudes are recorded when vertical jaw openings are between 15 and 20 mm [39]. Before each use, the bite fork was covered with a thin nylon sheet to protect the users from contamination (Figure 3).

Figure 3. The bite fork covered with a thin nylon sheet.

The bite forces (N) were calculated by the device and were displayed digitally. A cutoff value of 775 N was imposed to prevent tooth injury [14]. The accuracy and repeatability of this device has been validated previously [40].

All bite force readings were conducted by one examiner (G.P.). The intra-tester reliability was estimated using intra-class correlation (ICC) by the same examiner (G.P.) For measurements, all participants were asked to sit in an upright position without head support, with the Frankfort plane nearly parallel to the floor and feet resting on the floor. They were instructed to bite on the device as hard as they could until they felt pain and held for at least five seconds without moving the head [40].

The device was positioned between the subject's maxillary and mandibular teeth in such a way that the acrylic cone of the bite fork was placed side up on the palatal cusp of maxillary molars and pre-molars and on the buccal cusp of mandibular molar and pre-molar teeth (Figure 4).

Figure 4. The bite fork with the modification in the mouth.

All subjects were given the same standardized instructions in both a written and verbal form, before they started the procedure as following: "I am going to place this bite fork between your upper and lower posterior teeth in order to measure how hard you can bite. After the placement of the bite fork, I would like you to close your teeth together. When I signal you, please, increase your bite force slowly until you feel discomfort or pain and then relax. The bite force measurement from my signal to start should take about five seconds".

Each patient was tested in one or two posterior hemi arches; three occluding pairs (premolars and molars) were tested on each posterior hemi arch, with an interval of 30 s between the measurement of each occluding pair, in order to avoid the fatigue of masticatory muscles. The examiner (G.P) performed two repeated readings in each segment with a 5 min break between them, in order to determine the test-retest reliability. Therefore, every pair of occlusal unit received two readings and the highest reading, which represented the maximal bite force, was documented. In the test group, one antagonistic implant/tooth pair and two adjacent tooth/tooth pairs were tested. If there was more than one implant in the same posterior hemi arch, all implants were tested and the readings from all the implants were averaged.

2.3. Statistical Analysis

The collected data were analyzed using SPSS software (version 22.0; SPSS Inc., Chicago, IL, USA). Descriptive data were tabulated. Each hemi arch of the three occluding pairs measured was documented as three separate values (the highest reading for each pair of occlusal unit), and the mean value for every three occluding pairs on one side of the mouth was calculated. If there were three occluding pairs on each side of the mouth that met the inclusion criteria, the experiment was repeated and the results were documented as two separate observations (one for each side). Differences in the mean bite force of patients with and without dental implants were tested using the one-way ANOVA test. A cross-tabulation analysis was used to identify any trend between the groups. Sex relationships with the mean values of bite forces were analyzed in the two groups by two-way ANOVA. A significance level of $p \leq 0.05$ was used.

3. Results

Forty patients (20 females and 33 males) met the inclusion criteria and were included in the study. The mean ages for the test and the control groups were 47.9 ± 14.2 and 39.2 ± 9.8 years, respectively. A total of 53 experimental evaluations were performed. In 27 patients, one side of the mouth was measured, and in 13 patients, measurements were made on both sides.

The baseline characteristics of the subjects are presented in Table 1.

Table 1. Descriptive analysis of the patients' demographics.

		Group: Implant				Group: No Implant				Total				
		N	%	Mean	SD	N	%	Mean	SD	N	%	Mean	SD	P Val
Sex	male	14	42.4			19	57.6			33	100.0			NS
	female	9	45.0			11	55.0			20	100.0			
Age		23		47.9	14.2	30		39.2	9.8	53		43.0	12.6	0.030
Bruxism	No Parafunction	20	51.3			19	48.7			39	100.0			NS
	Probable Bruxer	2	33.3			4	66.7			6	100.0			
	Probable clencher	1	12.5			7	87.5			8	100.0			
Quantity		23		2.7	2.8	30				53		2.7	2.8	NS

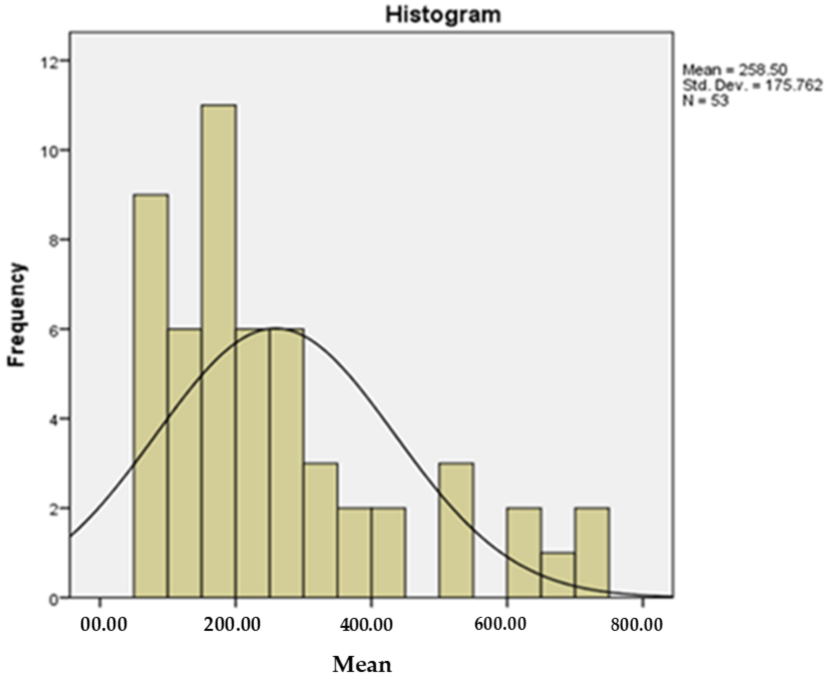
All implants were in the sites of premolars and molars. In the test group, there were only three subjects with more than three implants and 20 implants with 1–3 implants. All implants had occlusal contacts in the intercuspal position.

No discomfort or pain was experienced by subjects while biting on the instrument. The reliability analysis (ICC) result of 0.87 for the bite force measurements indicated a high consistency between the measurements performed on two different occasions by the same examiner (G.P.).

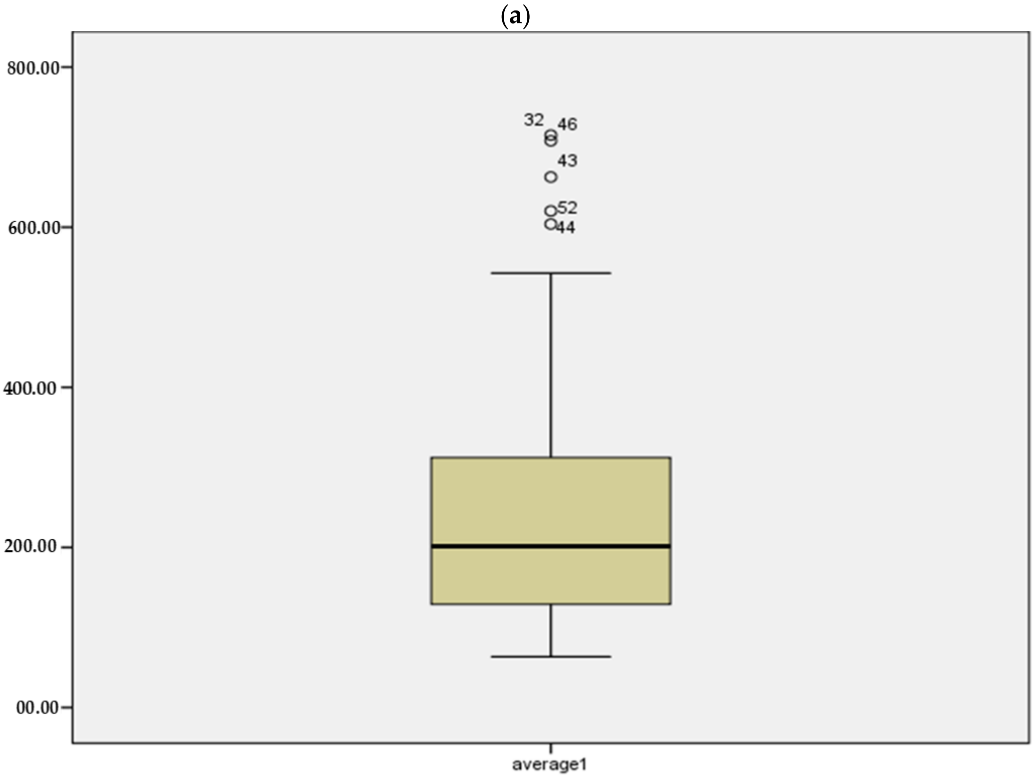
A histogram (Figure 5a) of the study population showed a skewed distribution of the average bite forces, where the "right tail" pattern reflected subjects with an "extremely high" occluding force (above 600 N). The mean bite force was 258.5 ± 175.8 N, while the median bite force was 201.3 ± 175.8 N, suggesting that there were fewer "extremely low" occluding force levels (below 100 N).

This can be seen more clearly when the "extreme" values are displayed in a "box plot" graph (Figure 5b), where the lines extending from the boxes (whiskers) indicate the variability outside the upper and lower quartiles.

The mean occlusal bite force among the members of the test group was lower (236.1 ± 162.3 N) than the mean occlusal bite force in the control group (275.7 ± 186.2 N), but the difference was not statistically significant ($p = 0.422$; Figure 6a).



(**a**)



(**b**)

Figure 5. (**a**) Mean bite force in the study; (**b**) median bite force in the study.

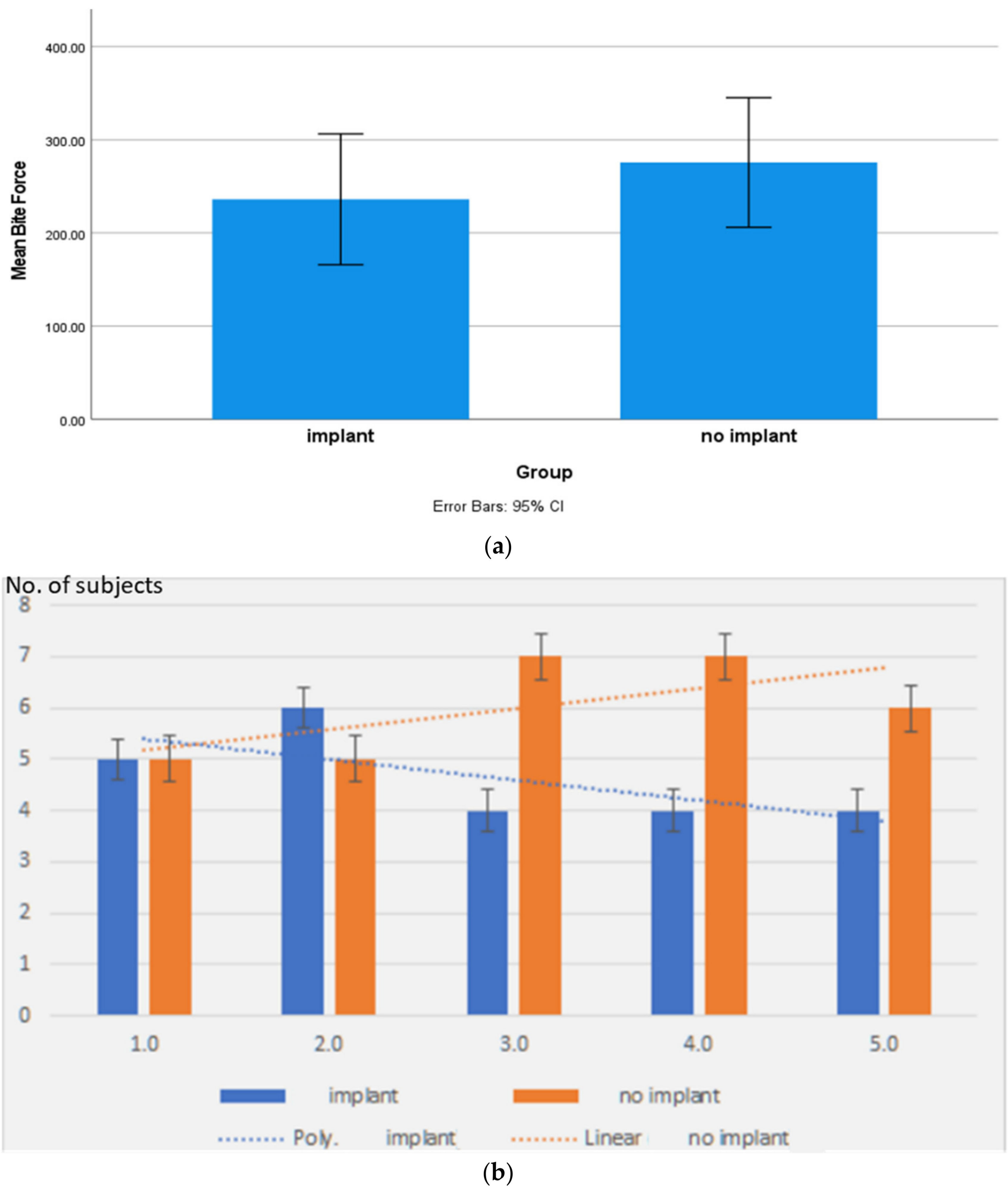


Figure 6. (**a**) Mean occlusal bite forces in the test and control groups; (**b**) cross-tabulation analysis. Implant represents the test group; no implant represents the control group.

The samples were arranged from the lowest bite force sample to the highest one, and then, the total list was divided into five equal groups. A cross-tabulation analysis, dividing the subjects into these five equal groups with the increasing bite force, revealed a clear trend between the test and control groups, with more members of the control group in the higher occlusal forces categories (Figure 6b).

A significant difference was detected between the maximal bite forces of male and female subjects ($p = 0.030$ in the implant group, $p = 0.010$ in the no-implant group), regardless of the experimental group (Figure 7).

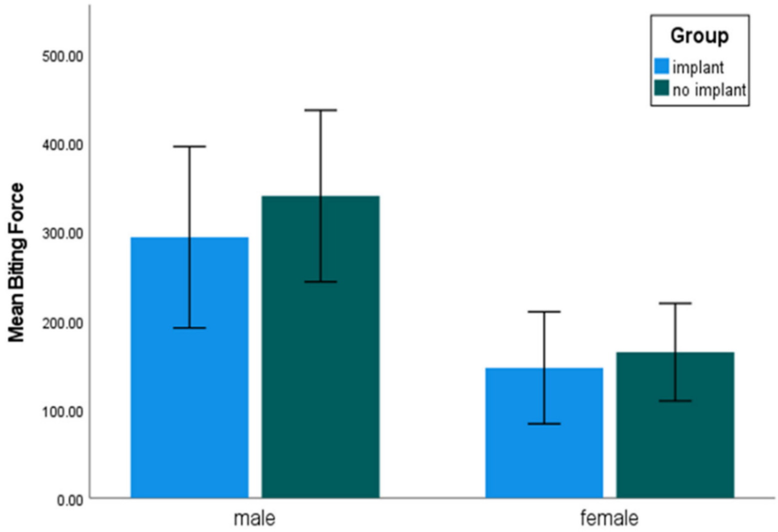


Figure 7. Mean maximal bite forces by sex and implant status.

Dividing the study population into four groups based on the number of implants (1, 2, 3, and above 3) did not reveal any significant difference in the bite force (p = 0.582; Table 2, Figure 8).

Table 2. Mean bite force and standard deviation (SD) according to the number of implants.

Number of Implants	Mean	N	SD
1	272.6	9	204.8
2	186.3	7	119.6
3	186.2	4	110.9
>3	309.3	3	182.1
Total	236.1	23	162.3

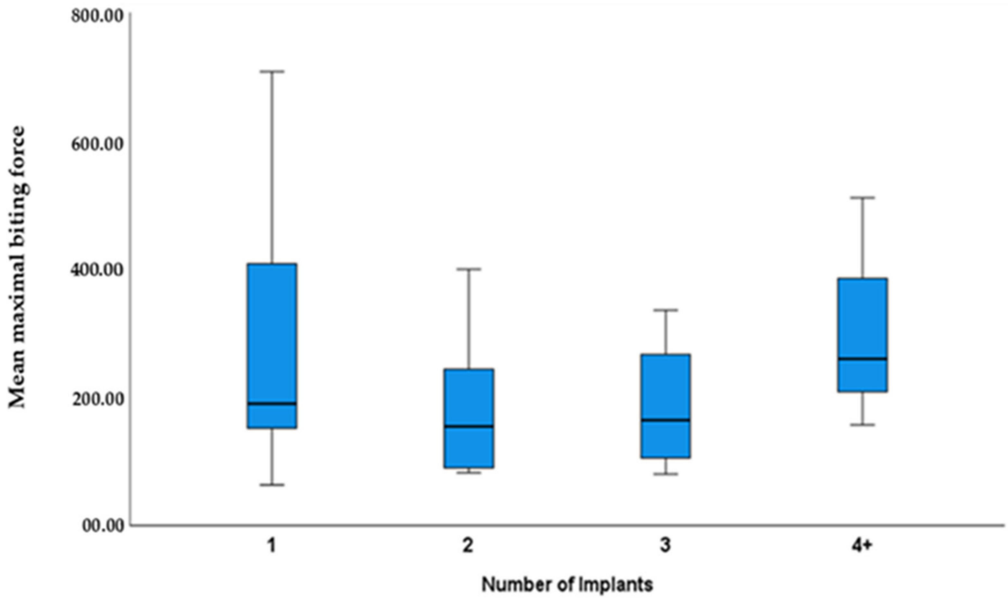


Figure 8. Box plot of the bite force by the number of implants.

Similarly, the presence of bruxism and clenching did not influence the bite force values, and no significant differences were found ($p = 0.953$) between the groups.

In addition, no significant difference was found in the bite force values between the age groups ($p = 0.393$; Figure 9).

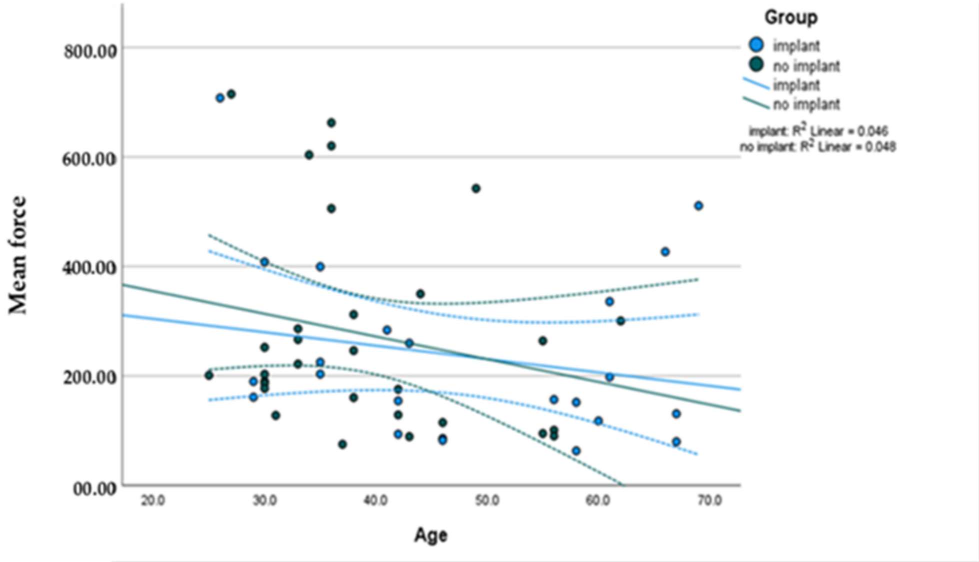


Figure 9. Mean maximal bite force by age and implants.

4. Discussion

This study was designed to evaluate the maximal bite force in patients with dental implants versus patients without dental implants, as measured by a digital bite force transducer (GM10). In addition, the influences of sex, age, and sleep/awake bruxsim on the maximal bite forces of the two groups were evaluated. Our null hypotheses were that there was no difference in the bite force in patients with or without dental implants and that the maximal bite forces of the two groups were not affected by sex, age, and sleep/awake bruxsim. Our null hypotheses were partially rejected.

Bite force may be an important parameter while planning implant-supported prosthesis, especially in patients with very high occlusal loads. A high bite force capability may predict a high risk for a late component fracture. Previous research showed that the results produced by the bite fork tool used in this study are robust between tests and between testers reliability [14]. The slight variability seen between testers suggests that it is preferable for a single examiner to collect mechanical threshold values [41], a conclusion that we implemented in the present clinical trial. The measurement of the force by the bite fork was also influenced by the position at which the force was applied. In our study, the cover of the bite fork was modified by attaching an acrylic cone, which acted as an occlusal guide. This enabled the placement of the bite fork in a standardized and reproducible position.

It should be noted that the reliability of bite force measurements may be influenced by individual factors that may alter the measurements including facial morphology, states of dentition, functional disturbances of the masticatory system such as the presence of pain and temporomandibular disorders, sex, age, craniofacial morphology, and occlusal factors [35].

There have been a number of studies that reported the measurement of the maximal bite force in normal subjects ranging from 244 to 859 N [42]. Interestingly, the mean maximal bite force in our study was relatively low (258.5 ± 175.7 N). Possible explanations for this finding include the small study population and the instructions given to our patients to stop biting when they felt discomfort or pain. In addition, the use of different devices, among the studies, with different biting elements may cause variations in the bite force measurements.

Notably, the surface of the bite fork was modified in the present study, such that it came into contact with only one cusp on the maxillary molar, while in previous studies the contact area between the force transducer and the teeth was much larger. Further explanations for the lower values are that muscle fatigue and psychological factors, such as a feeling of anxiety, and other factors, such as diet, habits, and profession, may significantly influence the measured values.

The mechanical properties of the bite force-recording system may affect the accuracy and precision of the bite force measurements. A histogram of the results from the current study population revealed a skewed distribution of the average bite force. The shape of the curve suggested that while there seemed to be a minimum bite force, the maximum values were more varied, thereby producing a right tail and non-normal distribution. Khan et al. showed the same tendency of the minimum subjects with an "extremely high" occluding force [15].

The results of the study suggested that the mechanical pain threshold was lower if implants were present. Although the differences did not reach significance, dividing the bite force measurements into five groups by ascending values, revealed a clear trend line with a stronger representation of the control group (no implants) in the higher force groups. We assumed that the pain is a summary of signals from all interacting sites. The loading forces during mastication induced by the masticatory muscles were controlled by the mechanoreceptors of the periodontal ligament. Therefore, reduced periodontal support (tooth loss and implants-less PDL) may decrease the threshold level of the mechanoreceptors function. On the other hand, remote mechanoreceptors can be responsible for the supra-threshold touch sensitivities of both teeth and implants [9]. These results are in agreement with those of Mericske-Stern et al. [43], who reported that the maximal occlusal force was significantly higher in subjects with natural dentition (control group) than in patients with fixed prostheses and implants (test group). Similarly, Miyaura et al. [44] found the highest bite forces in subjects with full natural dentition, while groups of individuals with fixed partial dentures, removable partial denture, and complete dentures exhibited biting forces of 80%, 35%, and 11%, respectively, when expressed as a percentage of the values in the natural dentition group. In contrast, Haraldson et al. [12] reported that patients with implant-supported bridges had an equal masticatory muscle function as control patients with natural teeth or with tooth-supported bridges. In view of the studies that demonstrated higher occluding forces on teeth adjacent to dental implants [23] and a higher incidence of VRFs in endodontically treated teeth adjacent to implants [24], our findings could be interpreted as a psychophysical fear of damaging abutment teeth, implants, or prostheses. This concern about causing damage or generating pain and tenderness in the teeth, supportive structures, temporomandibular joint, or masticatory muscles during the measurements might have a negative influence on bite force measurements [1]. There are other possible reasons that can generate discomfort biting on a successful dental implant. In the edentulous jaw or with implants, the activity of masticatory muscles and thus the bite force is monitored by mucosal and periosteal mechanoreceptors and not by receptors in the periodontal ligament [19]. Another reason can be the modified occlusion applied to implants in order to reduce the occlusal force during loading conditions, as well as the stress in the peri-implant surroundings [18]. Except for bite force measurements, there are other methods to evaluate quantitatively biomaterial biodegradation and bone formation around implants such as histomorphometry, microCT, microMRI, or the combination of them [45].

Our results demonstrated that sex has a significant influence on the maximal bite force, with higher values for men, regardless of the experimental group. This finding is in agreement with previous studies, which also have reported that the mean maximal bite force exerted by men is greater than that exerted by women [20,46,47]. This can be explained by the fact that females have smaller teeth, which corresponds to a smaller periodontal ligament area and consequently might deliver a lower bite force than seen in men. Another possible explanation could be the greater muscular potential of males, which may be attributed to the anatomic differences between different sexes [48]. In this context, the masseter muscles of males have muscle fibers with a larger diameter and a greater sectional area than those of females [49]. This result is of clinical relevance, because if so we might plan our treatment plan and select our materials differently in men and women.

The results of the current study did not reveal any significant difference in the bite force displayed by clenchers, bruxers, and normal occlusion subjects. Helkimo and Ingervall reported that individuals with clenching and grinding habits have a higher bite force only on incisors, but not on molars. Their explanation was that parafunctional habits are usually performed in non-centric positions when the required muscles of these positions are exercised (which occurs when the bite force is measured in the anterior quadrants) and not in a centric position (which occurs when bite force is measured in the posterior quadrants, as was conducted in our study) [50].

The limits of the current study are the small study population and the instructions given to our patients to stop biting when they felt discomfort or pain. In addition, no measurements of the bite force were performed, before the implants were rehabilitated. Since this study provides insufficient evidence to establish strong conclusions, it is a pilot study. Future well-designed studies with larger sample sizes are, therefore, required to determine unequivocally whether there is a true difference in the maximal bite force in patients with or without dental implants.

5. Conclusions

Within the limitations of this clinical pilot study, it may be assumed that there was no significant difference between the maximal bite force measured in patients with and without dental implants, but there was a trend line implicating a stronger representation of the "no implant" group in the higher strata of force results. In addition, there was a significant difference in the maximal bite force between different sexes, where males had a higher bite force, independent of the implant presence in the mouth.

The digital bite force transducer may be of clinical use in assessing masticatory forces and has the potential as a tool in prosthodontic planning and material selection, but further studies with larger sample sizes are warranted.

Author Contributions: Conceptualization, S.L., E.R. and I.T.; formal analysis, S.L., E.R. and I.T.; investigation, G.P. and S.M.; methodology, G.P., S.L. and E.R.; writing—original draft, G.P., S.L., E.R. and I.T; writing—review and editing, S.L., S.M., E.R. and I.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Approval was obtained from the Tel-Aviv University Institutional Ethical Committee (# 08410844_20180821) prior to data collection.

Informed Consent Statement: Written and oral informed consent was provided by all the participants.

Data Availability Statement: Data are available on request due to restrictions of privacy. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bakke, M. Bite force and occlusion. *Semin. Orthod.* **2006**, *12*, 120–126. [CrossRef]
2. Dos Santos Calderon, P.; Kogawa, E.M.; Lauris, J.R.P.; Conti, P.C.R. The influence of gender and bruxism on the human maximum bite force. *J. Appl. Oral Sci.* **2006**, *14*, 448–453. [CrossRef] [PubMed]
3. Johansson, A.S.; Svensson, K.G.; Trulsson, M. Impaired masticatory behavior in subjects with reduced periodontal tissue support. *J. Periodontol.* **2006**, *77*, 1491–1497. [CrossRef] [PubMed]
4. Klausen, B.; Helbo, M.; Dabelsteen, E. A differential diagnostic approach to the symptomatology of acute dental pain. *Oral Surg. Oral Med. Oral Pathol.* **1985**, *59*, 297–301. [CrossRef]
5. Cohen, S.; Liewehr, F. Diagnostic Procedures. In *Pathways of the Pulp*, 8th ed.; Cohen, S., Burns, R., Eds.; Mosby: St Louis, MO, USA, 2002; pp. 1–29.

6. Goldstein, G.; Goodacre, C.; Taylor, T. Occlusal Schemes for Implant Restorations: Best Evidence Consensus Statement. *J. Prosthodont.* **2021**, *30* (Suppl. 1), 84–90. [CrossRef]
7. D'Ercole, S.; D'Addazio, G.; Di Lodovico, S.; Traini, T.; Di Giulio, M.; Sinjari, B. Porphyromonas gingivalis load is balanced by 0.20% Chlorhexidine Gel. A randomized, double-blind, controlled, microbiological and immunohistochemical human study. *J. Clin. Med.* **2020**, *9*, 284. [CrossRef]
8. Mühlbradt, L.; Mattes, S.; Möhlmann, H.; Ulrich, R. Touch sensitivity of natural teeth and endosseous implants revealed by difference thresholds. *Int. J. Oral Maxillofac. Implant.* **1994**, *9*, 412–416.
9. Hsieh, W.W.; Luke, A.; Alster, J.; Saul Weiner, S. Sensory discrimination of teeth and implant-supported restorations. *Int. J. Oral Maxillofac. Implant.* **2010**, *25*, 146–152.
10. Ulrich, R.; Mühlbradt, L.; Möhlmann, H.; Schmid, H.; Hoss, A. Qualitative mechanoperception of natural teeth and endosseous implants. *Int. J. Oral Maxillofac. Implant.* **1993**, *8*, 173–178.
11. Mühlbradt, L.; Ulrich, R.; Möhlmann, H.; Schmid, H. Mechanoperception of natural teeth vs. endosseous implants revealed by magnitude estimation. *Int. J. Oral Maxillofac. Implants* **1989**, *4*, 125–130.
12. Haraldson, T.; Carlsson, G.E.; Ingervall, B. Functional state, bite force and postural muscle activity in patients with osseointegrated oral implant bridges. *Acta Odontol. Scand.* **1979**, *37*, 195–206. [CrossRef] [PubMed]
13. Lobbezoo, F.; Trulsson, M.; Jacobs, R.; Svensson, P.; Cadden, S.W.; van Steenberghe, D. Topical review: Modulation of trigeminal sensory input in humans: Mechanisms and clinical implications. *J. Orofac. Pain* **2002**, *16*, 9–21. [PubMed]
14. Khan, A.A.; McCreary, B.; Owatz, C.B.; Schindler, W.G.; Schwartz, S.A.; Keiser, K.; Hargreaves, K.M. The development of a diagnostic instrument for the measurement of mechanical allodynia. *J. Endod.* **2007**, *33*, 663–666. [CrossRef]
15. Khan, A.A.; Owatz, C.B.; Schindler, W.G.; Schwartz, S.A.; Keiser, K.; Hargreaves, K.M. Measurement of mechanical allodynia and local anesthetic efficacy in patients with irreversible pulpitis and acute periradicular periodontitis. *J. Endod.* **2007**, *33*, 796–799. [CrossRef] [PubMed]
16. Fontijn-Tekamp, F.A.; Slagter, A.P.; Bilt, V.D.; Van'T Hof, M.A.; Witter, D.J.; Kalk, W.; Jansen, J.A. Biting and chewing in overdentures, full dentures, and natural dentitions. *J. Dent. Res.* **2000**, *79*, 1519–1524. [CrossRef] [PubMed]
17. Fontijn-Tekamp, F.A.; Slagter, A.P.; van't Hof, A.; Kalk, W.; Jansen, J.A. Pain and instability during biting with mandibular implant-retained overdentures. *Clin. Oral Implant. Res.* **2001**, *12*, 46–51. [CrossRef]
18. Tawil, G. Peri-implant bone loss caused by occlusal overload: Repair of the peri-implant defect following correction of the traumatic occlusion. A case report. *Int. J. Oral Maxillofac. Implant.* **2008**, *23*, 153–157.
19. Jofre, J.; Hamada, T.; Nishimura, M.; Klattenhoff, C. The effect of maximum bite force on marginal bone loss of mini-implants supporting a mandibular overdenture: A randomized controlled trial. *Clin. Oral Implant. Res.* **2010**, *21*, 243–249. [CrossRef]
20. Flanagan, D. Bite force and dental implant treatment: A short review. *Med. Devices* **2017**, *10*, 141–148. [CrossRef]
21. Koyano, K.; Esaki, D. Occlusion on oral implants: Current clinical guidelines. *J. Oral Rehabil.* **2015**, *42*, 153–161. [CrossRef]
22. Sheridan, R.A.; Decker, A.M.; Plonka, A.B.; Wang, H.L. The role of occlusion in implant therapy: A comprehensive updated review. *Implant. Dent.* **2016**, *25*, 829–838. [CrossRef] [PubMed]
23. Lee, J.H.; Kweon, H.H.; Choi, S.H.; Kim, Y.T. Association between dental implants in the posterior region and traumatic occlusion in the adjacent premolars: A long-term follow-up clinical and radiographic analysis. *J. Periodontal Implant. Sci.* **2016**, *46*, 396–404. [CrossRef] [PubMed]
24. Rosen, E.; Beitlitum, I.; Tamse, A.; Taschieri, S.; Tsesis, I. Implant-associated vertical root fracture in adjacent endodontically treated teeth: A case series and systematic review. *J. Endod.* **2016**, *42*, 948–952. [CrossRef]
25. Rosen, E.; Goldberger, T.; Tamse, A.; Nemcovsky, C.; Breslauer, S.; Beitlitum, I.; Tsesis, I. Implant-associated cracked teeth: Case series evidence-based endodontics. *Evid. Based Endod.* **2017**, *2*, 1–5. [CrossRef]
26. Duqum, I.; Barker, S.; Marshall, E.; Wang, R.; John, S.; Preisser, J.S. The effect of single tooth implant restorations on the survival, morbidity, pulpal, and periapical health of adjacent teeth: A chart review. *Clin. Implant. Dent. Relat. Res.* **2018**, *20*, 479–482. [CrossRef] [PubMed]
27. Yoshino, K.; Nishibori, M.; Fujiseki, M.; Ito, K.; Kuroda, M.; Matsukubo, T. Loss of teeth in positions mesially adjacent to implant-supported fixed dentures: A retrospective clinical survey. *Int. J. Prosthodont.* **2015**, *28*, 158–160. [CrossRef] [PubMed]
28. Lobbezoo, F.; Ahlberg, J.; Glaros, A.G.; Kato, T.; Koyano, K.; Lavigne, G.J.; de Leeuw, R.; Manfredini, D.; Svensson, P.; Winocur, E. Bruxism defined and graded: An international consensus. *J. Oral Rehabil.* **2013**, *40*, 2–4. [CrossRef] [PubMed]
29. American Academy of Sleep Medicine. *The International Classification of Sleep Disorders: Diagnostic & Coding Manual*, 2nd ed.; American Academy of Sleep Medicine: Westchester, IL, USA, 2005.
30. Wintergerst, A.; López-Morales, M.P. Masticatory function in children with Down syndrome. *Physiol. Behav.* **2021**, *235*, 113390. [CrossRef]
31. Alam, M.K.; Alfawzan, A.A. Maximum voluntary molar bite force in subjects with malocclusion: Multifactor analysis. *J. Int. Med. Res.* **2020**, *48*, 300060520962943. [CrossRef]
32. Iwasaki, M.; Yoshihara, A.; Sato, N.; Sato, M.; Minagawa, K.; Shimada, M.; Nishimuta, M.; Ansai, T.; Yoshitake, Y.; Ono, T.; et al. A 5-year longitudinal study of association of maximum bite force with development of frailty in community-dwelling older adults. *J. Oral Rehabil.* **2018**, *45*, 17–24. [CrossRef]
33. Iwasaki, M.; Yoshihara, A.; Sato, N.; Sato, M.; Taylor, G.W.; Ansai, T.; Ono, T.; Miyazaki, H. Maximum bite force at age 70 years predicts all-cause mortality during the following 13 years in Japanese men. *J. Oral Rehabil.* **2016**, *43*, 565–574. [CrossRef] [PubMed]

34. Hirao, A.; Murata, S.; Murata, J.; Kubo, A.; Hachiya, M.; Asami, T. Relationships between the occlusal force and physical/cognitive functions of elderly females living in the community. *J. Phys. Ther. Sci.* **2014**, *26*, 1279–1282. [CrossRef] [PubMed]
35. Serra, C.M.; Manns, A.E. Bite force measurements with hard and soft bite surfaces. *J. Oral Rehabil.* **2013**, *40*, 563–568. [CrossRef]
36. Kamegai, T.; Tatsuki, T.; Nagano, H.; Mitsuhashi, H.; Kumeta, J.; Tatsuki, Y.; Kamegai, T.; Inaba, D. A determination of bite force in northern Japanese children. *Eur. J. Orthod.* **2005**, *27*, 53–57. [CrossRef] [PubMed]
37. Okada, Y.; Kamijo, Y.; Okazaki, K.; Masuki, S.; Goto, M.; Nose, H. Pressor responses to isometric biting are evoked by somatosensory receptors in periodontal tissue in humans. *J. Appl. Physiol.* **2009**, *107*, 531–539. [CrossRef] [PubMed]
38. Ohira, A.; Ono, Y.; Yano, N.; Takagi, Y. The effect of chewing exercise in preschool children on maximum bite force and masticatory performance. *Int. J. Paediatr. Dent.* **2012**, *22*, 146–153. [CrossRef] [PubMed]
39. Lindauer, S.J.; Gay, T.; Rendell, J. Effect of jaw opening on masticatory muscle EMG-force characteristics. *J. Dent. Res.* **1993**, *72*, 51–55. [CrossRef] [PubMed]
40. Verma, T.P.; Kumathalli, K.I.; Jain, V.; Kumar, R. Bite Force Recording Devices—A Review. *J. Clin. Diagn. Res.* **2017**, *11*, ZE01–ZE05. [CrossRef]
41. Tortopidis, D.; Lyons, M.F.; Baxendale, R.H.; Gilmour, W.H. The variability of bite force measurement between sessions, in different positions within the dental arch. *J. Oral Rehabil.* **1998**, *25*, 681–686. [CrossRef]
42. Cosme, D.C.; Baldisserotto, S.M.; Simone de Andrade, C.; Shinkai, R.S. Bruxism and voluntary maximal bite force in young dentate adults. *Int. J. Prosthodont.* **2005**, *18*, 328–332.
43. Mericske-Stern, R.; Assal, P.; Mericske, E.; Bürgin, W. Occlusal force and oral tactile sensibility measured in partially edentulous patients with ITI implants. *Int. J. Oral Maxillofac. Implant.* **1995**, *10*, 345–353. [CrossRef]
44. Miyaura, K.; Morita, M.; Matsuka, Y.; Yamashita, A.; Watanabe, T. Rehabilitation of biting abilities in patients with different types of dental prostheses. *J. Oral Rehabil.* **2000**, *27*, 1073–1076. [CrossRef] [PubMed]
45. Sinibaldi, R.; Conti, A.; Sinjari, B.; Spadone, S.; Pecci, R.; Palombo, M.; Komlev, V.S.; Ortore, M.G.; Tromba, G.; Capuani, S.; et al. Multimodal-3D imaging based on µMRI and µCT techniques bridges the gap with histology in visualization of the bone regeneration process. *J. Tissue Eng. Regen. Med.* **2018**, *12*, 750–761. [CrossRef] [PubMed]
46. Waltimo, A.; M Könönen, M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. *Scand. J. Dent. Res.* **1993**, *101*, 171–175. [CrossRef] [PubMed]
47. Koc, D.; Dogan, A.; Bek, B. Bite force and influential factors on bite force measurements: A literature review. *Eur. J. Dent.* **2010**, *4*, 223–232. [CrossRef] [PubMed]
48. Waltimo, A.; Könönen, M. Maximal bite force and its association with signs and symptoms of craniomandibular disorders in young Finnish non-patients. *Acta Odontol. Scand.* **1995**, *53*, 254–258. [CrossRef]
49. Bakke, M.; Holm, B.; Jensen, B.L.; Michler, L.; Möller, E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scand. *J. Dent. Res.* **1990**, *98*, 149–158.
50. Helkimo, E.; Ingervall, B. Bite force and functional state of the masticatory system in young men. *Swed. Dent. J.* **1978**, *2*, 167–175.