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Comparison of occlusal force distribution and digital occlusal analysis methods of single posterior implant restorations: an in vivo study

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Abstract

Background Occlusion plays a crucial role in maintaining masticatory function and temporomandibular joint (TMJ). Single implant supported restorations are widely used for posterior tooth replacement, but they require careful occlusal adjustment due to the absence of periodontal ligament. Digital occlusal analysis methods, such as digital impressions and Occlusense, provide quantitative assessments of occlusal contacts and force distribution. However, their accuracy and clinical relevance remain uncertain.

Methods In this prospective clinical study, occlusal force distribution was evaluated before and after placement of single implant supported restoration using the Medit i700 intraoral scanner and OccluSense system. Measurements were performed before and after prosthesis under standardised conditions. Occlusal contact areas and force distributions were analysed using CloudCompare and ImageJ software. Statistical analysis was performed using Kruskal–Wallis test and Kendall's Tau-B correlation analysis.

Results A total of 20 patients were included in the study. Post-restoration measurements revealed significant changes in occlusal force distribution in different segments of the dental arch ($p < 0.001$). Strong correlations were observed between Medit and OccluSense measurements ($p < 0.001$).

Conclusion Single-unit implant restorations significantly alter the occlusal force distribution, affecting not only the restored tooth but also the adjacent and opposing teeth. Both Medit i700 and OccluSense provided valuable information, with OccluSense providing a more detailed representation of occlusal force density. These findings suggest that digital occlusal analysis methods can help optimise occlusal adjustments for implant restorations.

Trial registration The current study was registered in ClinicalTrials.gov (ID: NCT06862973) First posted: 07/03/2025. Retrospectively registered.

Keywords Occlusion, Dental implant, Occlusal analysis, OccluSense, Medit i700

Background

The term occlusion is defined as the static and dynamic relationship between the teeth [1]. Stable occlusion is considered an important marker of masticatory and temporamandibular (TMJ) health [2]. The term occlusal stability can be defined as balanced occlusal contacts, absence of pain during function, absence of tooth loss, and an acceptable clinical vertical dimension [3]. The main purpose of prosthetic restorations in the presence of missing teeth is to restore lost occlusal relationships. One of the basic conditions for the success of the restoration is its integration with the dentomaxillary system [4]. Changes in force distribution that exceed the

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physiological limits of the individual can lead to various problems such as pain, tenderness, loss of the implant or temporomandibular disorders [5, 6].

Implant-supported single crown restorations are a frequently preferred treatment method for single tooth deficiencies [7]. Although they have high survival and success rates, they are not completely immune to complications. Due to the different nature of tooth and implant, adopting the same occlusal principles will lead to clinical complications [8]. The main difference is the absence of the periodontal ligament around the osteointegrated implant. This leads to excessive stress on the implant components when the principles of implant-protected occlusion are not adopted [9]. In order to reduce biomechanical stress in single-member implant-supported prostheses, maximum intercuspidation is desired in the neighbouring teeth and light contact in the related crown [10, 11]. However, in occlusion, which is a dynamic process, it is questionable how long this situation can be maintained after the delivery of the prosthesis, that is, its stability [11, 12]. In addition, the positive effect of this light contact condition on the whole jaw occlusal force distribution when combined with the complexity of the occlusion should also be questioned in single-tooth implant-supported prostheses. When the literature was examined, it was found that significant changes were observed in bilateral bite force distributions after the completion of posterior implant-supported restorations and studies reporting results that this force gradually increased in the implant-supported restoration [13, 14]. Previous studies have shown that single-tooth implant restorations not only offer a localized solution but also lead to biomechanical changes that can affect the entire masticatory system. A restoration achieved by placing an implant in the posterior region does more than simply restore the function of the missing tooth; it also influences the occlusal force patterns of the anterior and opposing arch teeth. This situation can alter the force distribution on the temporomandibular joint (TMJ), potentially increasing the risk of temporomandibular joint disorders in the long term. Therefore, evaluating occlusal force distribution after restoration is clinically critical not only for the success of the restoration itself but also for maintaining overall occlusal stability and temporomandibular joint health. Understanding the systemic effects of implant-supported restorations enables a more comprehensive approach to treatment planning [14–18]. In addition, recent clinical studies have demonstrated that variations in scanning components such as the use of scannable healing abutments versus conventional scan bodies as well as the choice of digital design software, can significantly affect the accuracy of interproximal and occlusal contacts in single posterior implant restorations. These findings emphasize the importance of further investigating how different digital occlusal analysis methods may influence occlusal force distribution and long-term occlusal stability following prosthetic rehabilitation [19, 20].

Traditional and digital methods can be used during the fitting of the restorations in the mouth. Among the traditional methods, articulation papers are the most frequently used in the clinic. This method, which only makes qualitative measurements, has various disadvantages and can be said to contain subjective data [21]. The size of the articulation paper does not give information about the magnitude of the force generated and is insufficient to interpret the load [22]. With the ever-increasing demand for digital dentistry, new digital devices are increasingly replacing traditional methods of recording occlusal contacts [23]. The digital methods are provided by a software application that provides the number of contacts present, the size of the contacted area and the amplitude of the generated force [24]. With these systems, both static and dynamic data of the occlusion can be obtained qualitatively and quantitatively [25].

Digital occlusal analysers are used to determine the position of occlusal contacts. The force percentages of the occlusal contacts are important quantitative data for alignments [26]. The recently launched OccluSense (Dr. Jean Bausch GmbH & Co. KG) offers the advantage of a sensor with built-in articulation paper that marks occlusal contacts directly on the teeth. In contrast to conventional methods, OccluSense records the distribution and intensity of the occlusal force as well as the exact moment of tooth contact [27]. The OccluSense system, with its sensor-integrated design, enables direct identification of occlusal contact points and represents contact force intensity through a color-coded scale and percentage values. Beyond merely detecting the presence of contact points, it facilitates a comprehensive analysis of their magnitude and spatial distribution, thereby producing a detailed representation of dynamic occlusal interactions. In this context, OccluSense serves as a functional alternative to articulating paper by offering both qualitative and quantitative insights [27].

Conversely, the Medit i700 functions primarily as a digital intraoral scanner, detecting occlusal contacts through software-based analysis. This system allows for the quantitative assessment of contact surface areas; however, it does not capture force intensity or the dynamic nature of occlusal function. While the Medit i700 excels in high-resolution visualization of occlusal morphology, it remains limited in terms of functional occlusal analysis, such as load distribution [28]. Another digital occlusal analysis method is the Medit Occlusion Analyzer software (Medit link version 3.1.4-Seoul, South Korea), an application developed by Medit to simplify dental occlusion analysis within CAD-CAM technology [29]. With the images obtained from the scans through intraoral scanners, the total contact areas of the teeth can be calculated and the change in the contact area after rehabilitation of the missing tooth can be evaluated.

Although intraoral scanners (IOSs) and OccluSense (Dr. Jean Bausch, GmbH & Co KG) are digital devices used to improve the clinical workflow, their reliability to record and analyse static and dynamic occlusal relationship is still uncertain.

The aim of this clinical study was to evaluate static and dynamic occlusal recordings using a Medit i700 intraoral scanner (Medit i700, MEDIT, Seoul, South Korea) and OccluSense, a digital occlusion analysis system (Bausch, Dr. Jean Bausch GmbH & Co KG, Cologne, Germany) and to examine the occlusal force distributions after completion of a single posterior implant supported restoration. Thus, it was aimed to demonstrate the effectiveness and functional performance of the current treatment.

The null hypotheses are: (1) there would be no significant difference in the bite force distributions after placement of single-member implant-supported restorations; (2) the recordings obtained with the intraoral scanner and OccluSense would be parallel.

Methods

Study design and ethical approval

This prospective clinical study was conducted at Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics. The study was approved by Necmettin Erbakan University Dentistry Drug and Non-Medical Device Research Ethics Committee (Decision number 471, dated 26.09.2024). Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

Sample size and power analysis

G*Power software (Version 3.1, Franz Faul, Universitat Kiel, Germany) was used to determine the sample size. Calculations were made considering $\alpha = 0.05$ significance level, $1\text{-}\beta = 0.90$ power value and 10% loss to follow-up. According to these criteria, the minimum number of patients to be included in the study was determined as 19 [15, 30].

Criteria for participation

Inclusion Criteria:

Individuals aged 18 and over
Patients with good periodontal health
Patients with a Angle Class 1 occlusion
Patients with a single tooth deficiency in the posterior region planned for rehabilitation with an implant-supported single crown restoration

Exclusion Criteria:

History of temporomandibular joint disease
Acute pain or signs of occlusal dysfunction
Restricted mouth opening
Absence of a tooth distal to the planned restoration
Occlusion instability due to prior orthodontic or surgical treatments

Patient assessment and measurement protocol

The measurements were taken at two different time points: before restoration placement (pre-prosthetic period) and after the restoration was completed (post-prosthetic period). For the measurements, the OccluSense (Dr. Jean Bausch GmbH & Co. KG, Cologne, Germany) and the Medit i700 intraoral scanner (Medit, Seoul, South Korea) were used. In both cases, the pre-prosthetic and post-prosthetic measurements were conducted in the morning of the same day to ensure that patients were not affected by diurnal variations. Post-prosthetic occlusal force recordings were obtained after the final occlusal adjustments of the restoration were completed to ensure accurate measurement of the functional occlusal contacts.

Standardization and calibration protocol

To minimize the margin of error and enhance measurement reliability, all measurements were conducted with patients seated in an upright position in the same dental chair. The measurements were performed by an experienced prosthodontist, while data analysis was carried out by a separate researcher. Before the study began, the dentists performing the measurements received training on the use of the OccluSense and Medit i700 systems. For calibration and standardization purposes, a single patient underwent 10 repeated measurements prior to the study, and the results were analyzed using the Image J software to ensure that the similarity between measurements exceeded 80% agreement.

All restoration designs were created by a single digital dental technician using the same digital design software (Exocad DentalCAD, version 3.1, Darmstadt, Germany) and following a standardized protocol. This approach ensured consistency and standardization across all designs.

Measurement protocol and data analysis

For standardization purposes, an appliance designed by Jauregi M. et al. [31] was reproduced in a similar format to establish the midline and anteroposterior reference

Fig. 1 The attachment used to ensure standardization during Occlusense recordings

points (Fig. 1). The device was calibrated before each patient. The recording mode was set to 100 Hz for 6 s, and patients were instructed to bite with maximum force. This ensured that recordings were taken in the maximum intercuspation position. Data analysis was based on the time frame with the highest number of contact points (Fig. 2).

Full-arch scans were taken using the Medit i700 digital scanner in accordance with the manufacturer's instructions and saved in STL format. The scans were recorded in parallel with the OccluSense measurements without changing the patient's position.

Data processing and analysis

The STL files obtained from the Medit i700 scanner were imported into Cloud Compare v2.13.1 (Paris, France) to generate occlusal contact surface maps (Fig. 3). Since the OccluSense sensor thickness is 60 µm, the surface map was adjusted to include only areas within this 60 µm threshold, excluding any regions beyond this distance. The OccluSense data were transferred to ImageJ 1.54f (Wayne Rasband & NIH, USA) software, where the contact point areas were calculated on a pixel basis.

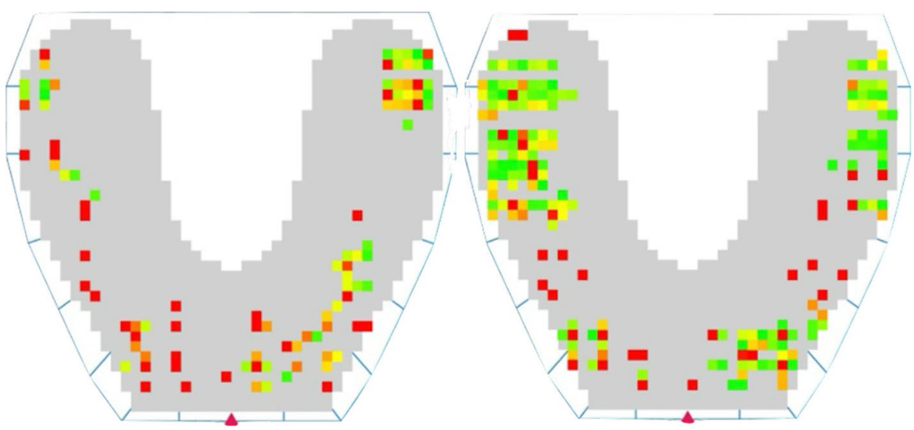

Fig. 2 Displays the pre-prosthetic and post-prosthetic Occlusense recordings

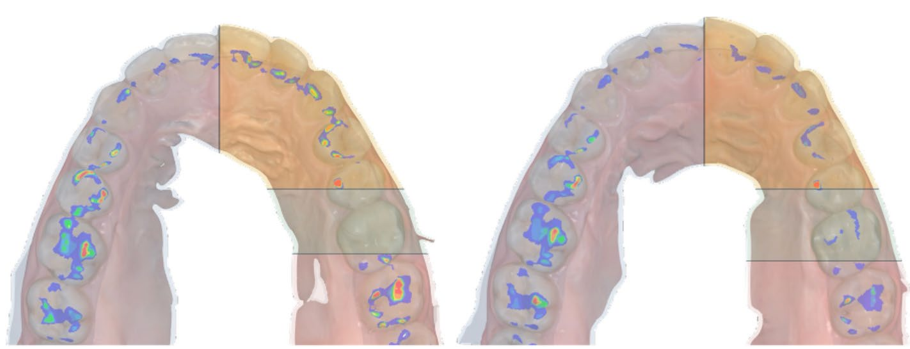

Fig. 3 Pre-prosthetic and post-prosthetic segmentation boundaries

The contact surfaces obtained using the Medit i700 scanner were categorized as M, while those obtained using OccluSense were divided into two groups: O1 for contact surfaces and O2 for force distribution. The measurement surfaces were classified into four groups:

Total Area (T), which includes the overall contact area
Anterior Area (A), extending from the mesial side of the restoration to the midline
Posterior Area (P), covering the region distal to the restoration
Opposing Arch Area (OP), which extends from the restoration to the midline of the opposing arch (Figure 4)

The percentage change between pre-prosthetic and post-prosthetic measurements was calculated for all these areas, while numerical values of area size were not assessed. In other words, the ratio of the total occlusal area to the occlusal contact area was analyzed.

Statistical analysis

The data were transferred to IBM SPSS Statistics 23 (IBM Corp., Armonk, NY, USA) for statistical analysis. Normality and homogeneity assumptions were assessed using the Shapiro–Wilk and Levene tests. Since the data did not follow a normal distribution, the Kruskal–Wallis test was applied ($p < 0.05$).

To determine differences between regions, the Dwass-Steel-Critchlow-Fligner (DSCF) test was used with Bonferroni correction. The agreement between measurement methods was evaluated using Kendall's Tau-B correlation analysis ($p < 0.05$).

Results

A total of 20 patients were included in the study. However, during the observation period, 2 patients who underwent procedures that could affect the measurement results were excluded from the study.

When evaluating the recorded results, it was observed that contact points were clearly visible in measurements taken using the intraoral scanner, but their intensities could not be analyzed. In contrast, measurements taken with OccluSense allowed for the analysis of force intensities both visually and in percentage terms, but the exact locations of the contact points were less distinct.

The percentage changes between pre-treatment and post-treatment data are presented in Table 1. Statistical analysis showed significant differences between the evaluated regions ($p < 0.001$, Table 2). In measurements taken using the intraoral scanner, contact areas in the anterior region decreased by 47.8 ±1.02%, while in the posterior region, they decreased by 65.5 ±1.39%. In contrast, contact areas in the opposing arch increased by 30.04 ±1.82%, and total contact areas increased by 17.66 ±1.09% (Fig. 5).

In measurements taken using OccluSense, contact areas in the opposing arch increased by 110.02 ±3.76%, and total contact areas increased by 36.71 ±1.92%. However, contact areas in the posterior region decreased by 34.39 ±0.8%, and in the anterior region, they decreased by 16.36 ±2.2% (Fig. 5). When evaluating force distribution changes using OccluSense, force distribution in the anterior region decreased by 18.54 ±1.58%, and in the posterior region, it decreased by 30.77 ±2.66%. On the other hand, total force distribution increased by 7.3 ±3.36%, and force distribution in the opposing arch increased by 30.29 ±4.82% (Fig. 5).

The correlation analysis performed to assess the consistency between different measurement methods revealed a high correlation between the Medit i700 and OccluSense measurements ($p < 0.001$, Table 3).

Discussion

Based on the results of the study, changes in contact surface areas and contact intensity were observed between segments following single-tooth implant restorations. When examining the variations in measurements obtained through different methods, a correlation was

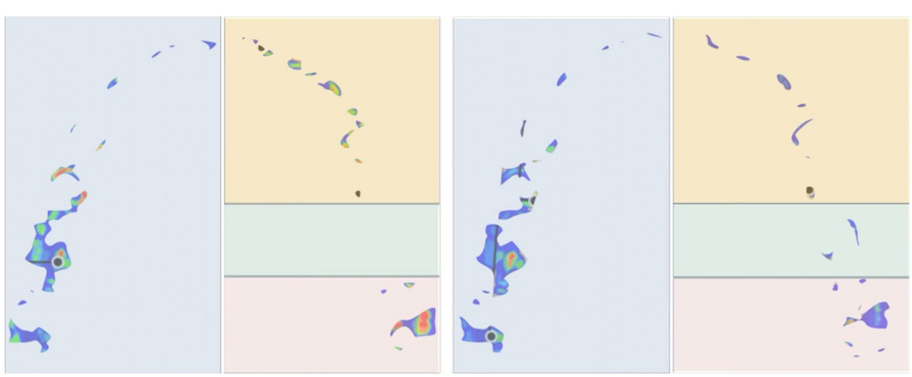

Fig. 4 Separation of occlusal contacts from the model

Table 1 Descriptive statistics of measurement values and Shapiro–Wilk Test Results

Method	Region	N	Median	SD	Minimum	Maximum	Shapiro- Wilk	
							W	p
M	T	18	17.66	1.096	15.030	19.67	0.958	0.573
	A	18	−47.80	1.026	−49.325	−45.91	0.963	0.670
	P	18	−65.50	1.390	−67.759	−63.22	0.962	0.646
	OP	18	30.04	1.829	27.373	33.66	0.958	0.562
O1	T	18	36.71	1.924	33.318	40.18	0.978	0.930
	A	18	−16.36	2.200	−17.660	−9.00	0.821	0.003
	P	18	−34.39	0.821	−36.230	−33.04	0.950	0.432
	OP	18	110.12	3.766	101.560	113.99	0.944	0.335
O2	T	18	7.30	3.368	0.375	13.40	0.961	0.617
	A	18	−18.54	1.585	−21.840	−15.74	0.990	0.999
	P	18	−30.77	2.663	−36.055	−26.92	0.962	0.650
	OP	18	30.29	4.824	24.745	44.45	0.914	0.102

Descriptive statistics and Shapiro–Wilk normality test results for Medit i700 (M) and OccluSense measurements (O1: contact surface area, O2: percentage force distribution) across different regions (T: total contact area, A: anterior region, P: posterior region, OP: opposing arch). A p-value < 0.05 indicates a deviation from normal distribution, while a p-value > 0.05 suggests that the data follow a normal distribution

Table 2 Results of the Dwass-Steel-Critchlow-Fligner (DSCF) Test

Method Segment	M		O1		O2	
	W	p	W	p	W	p
T – A	−7.25	<.001	−7.25	<.001	−7.25	<.001
T – P	−7.25	<.001	−7.25	<.001	−7.25	<.001
T – OP	7.25	<.001	7.25	<.001	7.25	<.001
A – P	−7.25	<.001	−7.25	<.001	−7.25	<.001
A – OP	7.25	<.001	7.25	<.001	7.25	<.001
P – OP	7.25	<.001	7.25	<.001	7.25	<.001

Statistical differences between segments were evaluated for different measurement methods (M: Medit i700, O1: Occlusense contact surface, O2: Occlusense force distribution). The obtained p-values (< 0.001) indicate significant differences in all comparisons. Notable differences were identified between the total contact area (T) and the anterior (A) and posterior (P) regions, as well as between the posterior (P) region and the opposing arch (OP) region

found between the results. In light of these findings, H1 was rejected, while H2 was accepted.

This study analyzes how occlusal forces and contact areas change following single-tooth implant restorations. The findings indicate that significant changes occur in occlusal contact surfaces and force intensity after implant-supported restorations. Notably, the increase in contact surfaces may help distribute chewing forces over a broader area, contributing to the maintenance of occlusal balance [32]. However, improper occlusal contacts can negatively impact the success of restorations and lead to unfavorable changes in chewing function. The findings suggest that force distribution across the entire arch changes after a single-tooth restoration, which may result in significant long-term biomechanical effects. Excessive load in cases where balanced occlusion is not achieved can not only lead to the failure of the implant itself but also contribute to temporomandibular joint dysfunction over time [33].

The OccluSense system provides data on the distribution of occlusal forces, the surface area over which these forces are distributed (contact surface), the dynamics of occlusal contacts, and the distribution ratio between the two halves of the dental arch. According to the color-coded representation of occlusal force amplitudes, red indicates high-amplitude occlusal forces, green represents normal occlusal forces, and yellow signifies minimal-intensity occlusal forces [27]. In the recordings obtained using the Medit i700, the color map reflects changes based on the distance between the two arches rather than the distribution of forces. This methodological difference makes direct comparison between the two systems challenging. Therefore, in the analyses, changes in measurement surface areas were considered instead of color variations [33].

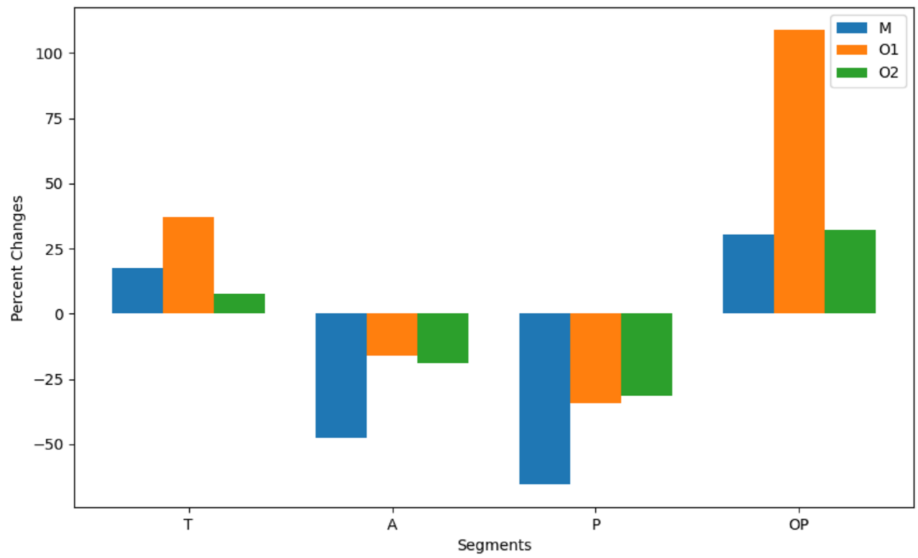

Fig. 5 Bar chart showing the percentage changes according to different methods and segmentations (T: Total, A: Anterior, P: Posterior, OP: Opposing arch, M: Medit contact area, O1: Occlusense contact area, O2: Occlusense Force)

Table 3 Results of Kendall's Tau B Correlation Analysis

Method	Kendall's Tau B	*p*-value
M—O1	0.751***	<.001
M—O2	0.769***	<.001
O1—O2	0.763***	<.001

Evaluating the correlation between Medit i700 (M), Occlusense contact surface (O1), and Occlusense force distribution (O2) measurements. The obtained correlation coefficients (0.751, 0.769, and 0.763) indicate a strong positive relationship ($p < 0.001$)

According to the study results, a significant increase in total surface areas was observed in measurements taken with both the Medit i700 and OccluSense systems. Similarly, an increase in force distribution was also noted. The expansion of contact surfaces contributes to an increase in chewing force and efficiency [2, 34]. Since the surface area over which forces are distributed increases in the restored hemi-arch after restoration, it can be inferred that the percentage of force on the teeth located anterior and posterior to the restoration has decreased.

When examining contact areas and forces, the reduction in the posterior region was found to be significantly greater than in the anterior region ($p < 0.001$). When there is a missing tooth in the posterior region, the occlusal load distribution becomes unbalanced. Due to the absence of these teeth, the force exerted on the remaining posterior teeth increases. Additionally, since the posterior region is the first to make contact during jaw closure, the load on these teeth may be further amplified [35–37]. To prevent such an imbalance, it is crucial to rehabilitate missing teeth. Additionally, conducting an occlusion analysis is necessary to determine appropriate contact points. When the load distribution between the anterior and posterior teeth is disrupted, temporomandibular joint dysfunction may occur due to occlusal trauma [38, 39].

In a study by Zhou T et al. (2021) examining changes in occlusal forces following single-unit implant-supported restorations, a decrease in force within the anterior segment was observed, similar to our findings. This can be explained by the increased role of posterior teeth during maximum intercuspation and the restoration of missing teeth, which leads to an increase in contact points and surface area in the posterior region. Consequently, this redistribution of pressure reduces the force transmitted to the anterior segment [15]. This indicates that implant-supported restorations not only affect local occlusion but also alter the overall occlusal balance.

The obtained results demonstrate that chewing forces change over time after the completion of implant-supported restorations and that their distribution is reshaped [14, 15, 40]. Specifically, while a decrease was observed in the measured contact areas in the anterior and posterior regions, an increase was noted in the opposing arch and total contact areas. These findings support similar studies in the literature. For example, Kim et al. (2021) reported an increase in occlusal force in the contralateral arch after the completion of posterior single-implant restorations. Similarly, Roque et al. (2017) found that occlusal pressures were redistributed over time after implant-supported restorations during jaw closure and that the adaptation process varied among patients [14, 40].

In our study, a similar increase in both force and contact area was observed in the opposing arch during postoperative recordings. This can be attributed to the balancing of occlusion and the bilateral distribution of forces, leading to increased functional efficiency in the opposing arch. However, it should be considered that, in the early post-prosthetic phase, this redistribution of forces may cause excessive loading on the muscle groups and joint structures of the opposing side, potentially leading to asymmetry and temporomandibular joint discomfort [16]. Therefore, evaluating patients'chewing dynamics during post-implant follow-ups and detecting potential temporomandibular joint (TMJ) problems at an early stage is of great importance.

However, some studies have observed an increase in load in the posterior segment, which has been attributed to the occlusal adaptation process following restoration [33].

Our study findings suggest that a decrease in load may be observed in the posterior segment, particularly during the initial adaptation period following implant placement, and that patients may gradually reshape their chewing patterns over time. Therefore, long-term follow-up studies are needed.

The variability in patients's individual chewing habits is an important factor to consider in such studies. Patients may unconsciously avoid chewing on the implant-treated side, which can lead to a gradual reshaping of occlusal forces over time. To better understand the impact of chewing habits and implant placement on occlusal forces, studies with larger sample sizes are needed. [16]

The limitations of this study include the relatively small sample size. Future studies with larger patient groups and long-term follow-ups will contribute to a better understanding of post-implant occlusal force changes. Additionally, individual chewing habits and the tendency to avoid the implant region were not considered, and the impact of these factors on force distribution over time should be evaluated in future research. Since the Medit i700 and OccluSense systems analyze different parameters, their direct comparison is limited and may involve methodological differences.

Furthermore, this study focused solely on single-tooth implant restorations, highlighting the need for further research that includes multiple implant rehabilitations and full-arch prostheses. Lastly, the measurements were taken in a controlled clinical environment, meaning that the dynamic changes occurring during daily functional chewing were not fully assessed.

In addition, conventional methods such as articulating paper were not included in this study. This decision was based on the aim to specifically assess the intra-method reliability and consistency between digital occlusal analysis systems. Given the fundamental methodological differences between conventional and digital techniques, their direct comparison was considered outside the scope of this study.

However, future research that integrates both digital and traditional approaches may provide a more comprehensive understanding of occlusal assessment methods in clinical settings. Furthermore, long-term studies evaluating natural masticatory function under real-life conditions are recommended to enhance the clinical relevance of these findings.

Conclusion

The results obtained within the limitations of this study are as follows:

After the completion of single implant-supported restorations, significant changes in force distribution are observed not only in the area of the restoration but also throughout the entire dental arch.

The data obtained from examinations using OcluSense and Medit i700 correlate with each other, and the force amplitude data provided by OcluSense may be a more practical choice during the occlusal adjustment process of the restoration in the clinic.

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None.

Authors' contributions
NG, MG participated in designing the study. MG participated in generating the data for the study. NG participated in gathering the data for the study. NG and MG participated in the analysis of the data. MG and NG have had access to all the raw data of the study. MG have reviewed the pertinent raw data on which the results and conclusions of this study are based. NG and MG have approved the final version of this paper. NG and MG guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by Necmettin Erbakan University Dentistry Drug and Non-Medical Device Research Ethics Committee with decision number 471 dated 26.09.2024. Informed consent form was obtained from all individuals participating in the study. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

Consent for publication
All participants provided written informed consent for the publication of anonymized clinical data and any accompanying images, in accordance with institutional guidelines and the Declaration of Helsinki.

Competing interests
The authors declare no competing interests.

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