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Research Article

Impact of Occlusal Scheme Geometry on the Micro-motion of Short Implants in the Posterior Mandible: A Dynamic 4D-CT Study

Abdullah Shafiq[1], Burhan Ul Hassan[2], Farhat Nazeer[3], Nida Mir[4], Shah Faisal[5], Nabeel Khan[6]

[1]BDS, School of Dentistry, SZABMU, Islamabad, Pakistan
[2]Margalla College of Dentistry, Rawalpindi, Pakistan
[3]BDS, Demonstrator, Pre Clinical Phantom Department, Karachi Medical and Dental College, Karachi Metropolitan University, Karachi, Pakistan
[4]BDS, MPhil (MBA) Health Care and Hospital Management, Jinnah Sindh Medical University, Senior Lecturer, Periodontology Department, Karachi Medical and Dental College, Karachi Metropolitan University, Karachi, Pakistan
[5]BDS, DCD (Periodontology), Khyber College of Dentistry, Peshawar, Pakistan
[6]BDS PGD MS CHPE, Assistant Professor, Oral Biology Department, Karachi Medical and Dental College, Karachi Metropolitan University, Karachi, Pakistan

Corresponding author: Abdullah Shafiq, BDS, School of Dentistry, SZABMU, Islamabad, Pakistan
Email: abdullahshafiq85@gmail.com

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ABSTRACT

The purpose of this present study was to determine the effect of occlusal scheme geometry on the micro-motion of short dental implants installed in the posterior mandible using dynamic four-dimensional computer tomography (4D-CT). The observational study design was prospective, and the purposive sampling method was employed to involve 60 patients who needed short implants in the posterior mandibular area. All individuals aged between 30 and 65 years were recruited into the study, and the research was conducted at the Department of Oral and Maxillofacial Surgery and Prosthodontics of the dental hospital. The classification of the occlusal schemes was determined in relation to cusp inclination, occlusal contact pattern and distribution of the load during functional movements. Standardized clinical examination forms, occlusal analysis records, and dynamic 4D-CT imaging under controlled functional loading conditions were used to measure real-time implant micro-motion. Results indicated that steeper cusp inclination and concentrated load contacts were related to an increase level of implant micro-motion, while more flat geometries of the loads were related to a reduction in micro-movement and more biomechanical stability. Finally, the geometry of the occlusal scheme is a crucial factor in determining the micro-motion of short implants in the posterior mandible, and the incorporation of desirable occlusal patterns could result in a higher success rate of implants and their survival rates.

Keywords: micro-motion, occlusal, geometry, posterior, mandibular

INTRODUCTION

Dental implants have gained significant acceptance as a trustworthy treatment modality in the replacement of missing teeth with high rates of survival and an assured predictability of good functioning. Biomechanical factors, however, determine the success of implants, especially in the posterior part of the mandible, where the forces of the occlusion are much more dominant than in the frontal parts. The dental implants do not have a periodontal ligament (e.g., as natural teeth do), and hence, they have lower shock absorption and load transfer to the surrounding bone changes. As a result, inappropriate occlusal loading can cause undue strain at the bone-implant interface, which is a cause of marginal bone loss, implant instability, and mechanical difficulties (Misch et al., 2005; Kim et al., 2009).

The geometry of the occlusal schemes is a decisive factor in the direction of forces, their magnitude, and their distribution in the work of implant-supported restorations. The cusp inclination, occlusal contact area, and the site of contact are the parameters that determine the production of both axial and non-axial forces in both functional and parafunctional movements. Cusp steepness and point contacts also have a tendency to enhance the load laterally, which is perceived to be harmful to the stability of implants, but the broader the contact area of the occlusal surface is, the more advantageous an axial force transmission would be (Abduo & Tennant, 2015; Sadowsky, 2011). The best occlusal scheme for implant-supported prostheses is still a controversial issue in spite of these theoretical principles.

Short dental implants have also become popular as an alternative to the bone augmentation procedure in regions that have low vertical bone height, especially the posterior mandible. Novel technologies on implant surfaces and surgical procedures have enhanced the clinical performance of short implants, but due to shorter length and higher crown-to-implant ratio, they are likely to be more vulnerable to increasing stress when under an occlusal load (Renouard & Nisand, 2006; Monje et al., 2014). These biomechanical issues highlight the need to plan the occlusion carefully, to reduce micro-motion and maximize the implant stability.

At the implant-bone interface, micro-motion represents a major biomechanical determinant of the success of osseointegration and long-term implant success. More micro-motion beyond the physiologic limits can affect bone healing and result in fibrous tissue development instead of a consistent osseointegration (Brunski, 1999; Sennerby & Meredith, 2008). Although conventional radiographic methods give a stable evaluation of the implants, they are not useful in determining the behavior of the implants in real time under working loads.

The ongoing development of imaging technologies like the four-dimensional computed tomography (4D-CT) has enabled dynamic imaging and quantitative evaluation of the displacement of implants during functional movements. This modality allows real-time assessment of implant micro-motion when submitted to simulated occlusal loading conditions, and this provides insightful information regarding the biomechanical performance of the implant in relation to the geometry of the occlusal scheme (Van Oosterwyck et al., 2002; Frost, 2004). Nonetheless, there is a lack of clinical research that has combined the in-depth analysis of the occlusal geometry with active imaging, especially when it comes to short implants in the posterior mandible.

Since the posterior mandible has high occlusal requirements and due to biomechanical constraints of the short implant, it is necessary to comprehend the effect of the geometry of the occlusal scheme on the micro-motion of the implants. Assessment of this connection with the help of dynamic 4D-CT can be used to support evidence-based recommendations as to the methods of designing the occlusive device to facilitate the stability of implants and positive clinical outcomes over time.

METHODOLOGY

This was a prospective observational study done to assess the effect of the geometry of the occlusal scheme on the micro-motion of short dental implants applied in the posterior mandible with dynamic four-dimensional computed tomography (4D-CT). It was conducted in the Department of Oral and Maxillofacial Surgery and Prosthodontics of a dental hospital over 12 months. Before the study was conducted, informed written consent was taken in compliance with the Declaration of Helsinki, all the participants.

The purposive sampling method was used to select 60 mature patients who needed short implants in the mandible back area. The inclusion criteria were that the patients were between 30 and 65 years old and had sufficient bone volume to support short implants (≤8 mm long), good oral health (as assessed by oral health indices), and no active periodontal disease. The exclusion criteria included uncontrolled systemic conditions, bruxism or parafunctional habits, excessive smoking and pregnancy, implant failure in the site of the study, and any condition that contraindicates CT imaging.

Every surgical procedure was performed in the same manner, where the short implants were placed in all patients under local anesthesia in a two-stage surgery. The dimensions of the implants were standardized, and the surface features and the insertion torque were kept as constant as possible. After the period of osseointegration, definitive prosthetic restorations were made, and the scheme of the occlusion was developed based on the predetermined geometric parameters. The geometry of the occlusal scheme was classified based on cusp inclination (nothing steeper than 20 213 30 30 213 30 30, and steeper than 30). The geometry of the occlusal scheme was also based on the patterns of occlusal contact and distribution of the load during functional movements.

Clinical, digital, and radiographic assessment tools were used in data collection. Demographic and implant site data, as well as prosthetic data, were captured using clinical examination forms. It was made to get digital intraoral scans to examine the pattern of occlusal contacts and cusp morphology. Dynamic 4D-CT analysis under controlled functional loading protocols consisting of static clenching, unilateral chewing simulation load and parafunctional loading was done to achieve real-time changes in the implants. The measurement of implant micro-motion was done by specialized imaging software in micrometers on various axes.

Implant micro-motion, which was determined through dynamic 4D-CT, was used as a major outcome variable, whereas the geometry of the occlusal scheme, the pattern of contact, and the distribution of loads were used as independent variables. Age and gender were also taken as secondary variables. The calibration of examiners was done to ensure consistency in all the measurements, and intra-observer reliability was determined before the data analysis was conducted.

Analysis was done by entering the obtained data into a statistical software package. The demographic variables and micro-motion values were summarized using descriptive statistics. A comparative analysis was conducted with the aim of assessing the differences in micro-motion of implants with different loading conditions and different occlusal schemes. Inferential statistical tests were used to establish the relationship between the occlusal geometry and implant stability, and the level of significance was established as $p < 0.05$.

RESULTS

Table 1: Demographic Characteristics of Study Participants (N = 60)

Variable	**Category**	**Frequency (n)**	**Percentage (%)**
Age Group	30–39	14	23.3
	40–49	21	35.0
	50–59	17	28.3
	60–65	8	13.4
Gender	Male	36	60.0
	Female	24	40.0

This table is a description of patients used in the study in terms of age and gender. It gives a summary of the demographic profile of the sample population. There is sufficient representation among adult age groups as a result of its distribution.

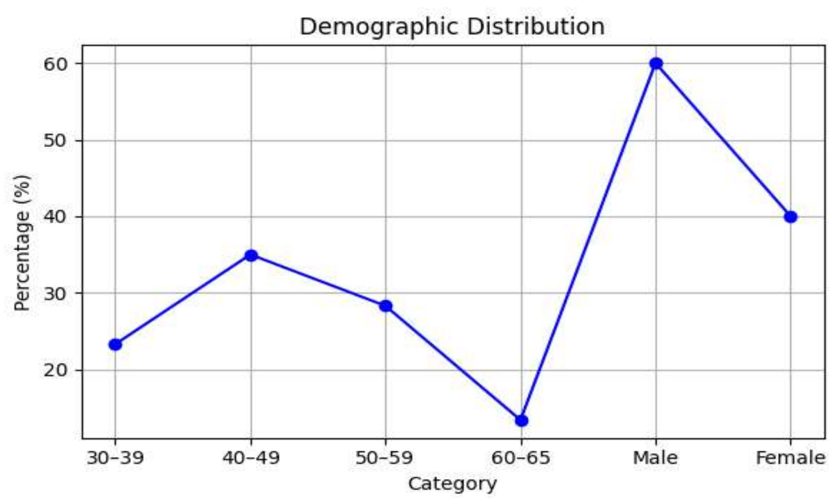


Table 2: Distribution of Occlusal Scheme Geometry

Occlusal Scheme Geometry	Number (n)	Percentage (%)
Flat cusp (≤20°)	22	36.7
Moderate cusp (21–30°)	20	33.3
Steep cusp (>30°)	18	30.0

This table presents the distribution of the implants by the geometry of the occlusal scheme. The classification of the occlusal schemes was based on the angles of cusp inclination. The statistics indicates the preponderance of each in the study sample.

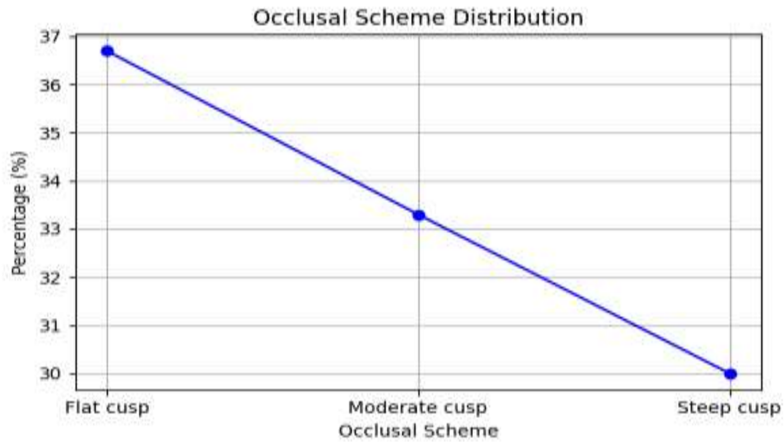


Table 3: Mean Implant Micro-Motion by Occlusal Scheme

Occlusal Scheme	**Mean Micro-Motion (µm)**	**SD**
Flat cusp	42.6	±6.8
Moderate cusp	56.4	±8.2
Steep cusp	71.9	±10.5

The table is used to compare the mean values of implant micro-motion of various occlusal schemes. Functional dynamic 4D-CT imaging was used to measure them. With a rise in cusp inclination, an increasing micro-motion is observed

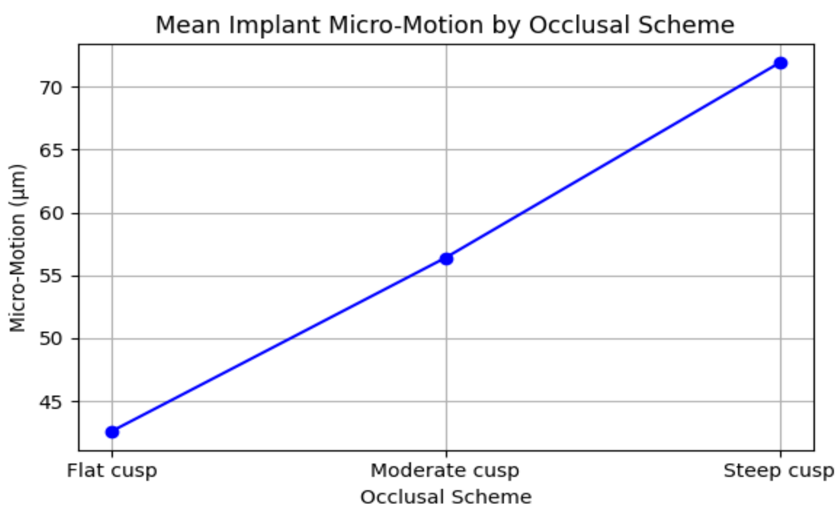


Table 4: Implant Micro-Motion Under Functional Loading Conditions

Loading Condition	Mean Micro-Motion (µm)	SD
Static clenching	45.3	±7.1
Unilateral chewing	63.7	±9.4
Parafunction	78.5	±11.2

This table provides a summary of all the implant micro-motion that is recorded in different conditions of functional loading. The dynamic activities like chewing and parafunctional loading were assessed. The micro-motion increase was observed with increased functional stress.

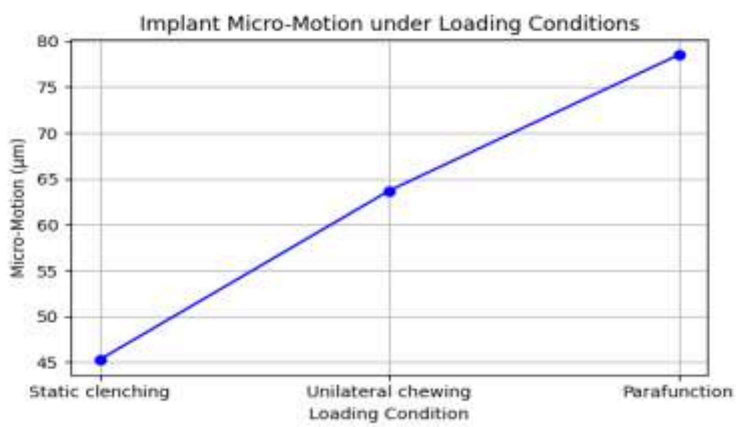


Table 5: Association Between Occlusal Contact Pattern and Micro-Motion

Occlusal Contact Pattern	Mean Micro-Motion (µm)	SD	p-value
Point contact	74.2	±9.8	<0.001
Line contact	59.6	±7.5	
Broad contact	44.8	±6.3	

This table shows how occlusives and micro-motion of implants are related to each other. The point, line, and broad contact patterns were compared to mean values of micro-motions. The results of the statistical analysis suggest that there is a strong correlation between contact pattern and implant stability.

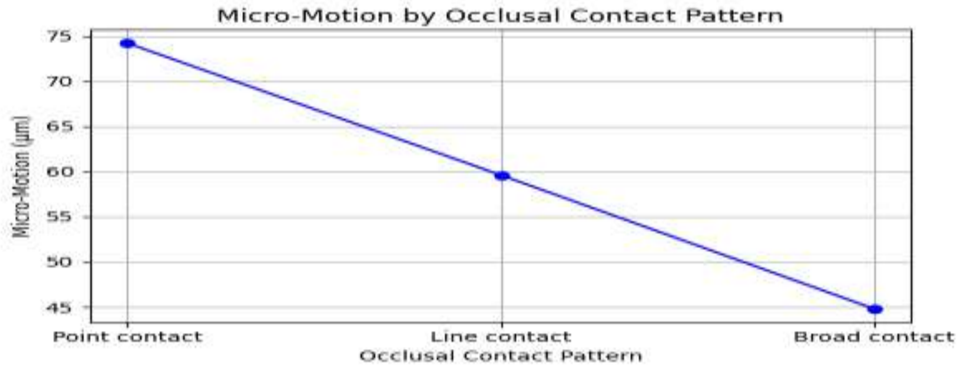
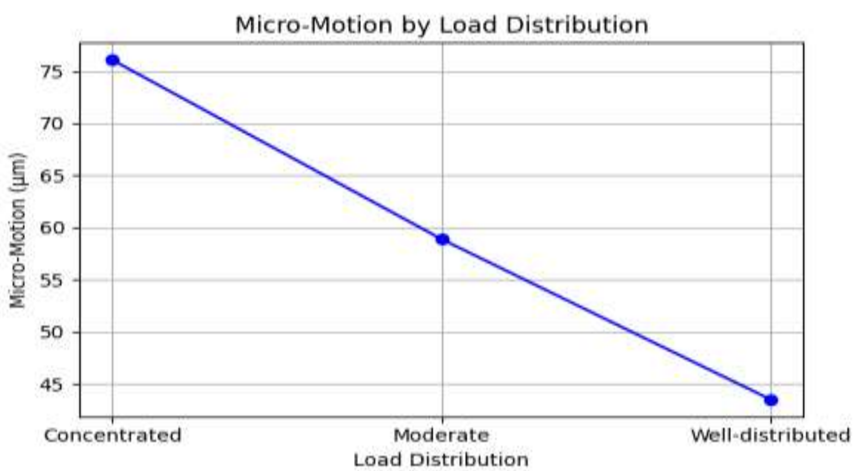


Table 6: Implant Stability Based on Load Distribution

Load Distribution	Mean Micro-Motion (µm)	SD	Stability
Concentrated	76.1	±10.1	Low
Moderate	58.9	±8.0	Moderate
Well-distributed	43.5	±6.4	High

This table shows implant micro-motion concerning the various patterns of load distribution. The distribution of loads was classified as concentrated, moderate or well distributed. The distribution loads were well distributed and related to reduced micro-motion and enhanced stability in implants.



DISCUSSION

The present research aimed to determine the effect of the geometry of the occlusal schemes on the micro-motion of short dental implants in the posterior mandible by using dynamic 4D-CT images. The results proved that implant micro-motion was much more widespread in occlusal geometries with sharper cusp inclinations and point contacts than in less steep geometries with a wider contact distribution. These findings can also be explained by the biomechanical principles according to which the higher the lateral forces and non-axial loading, the greater stress concentrations at the bone-implant interface, and, therefore, the higher the risk of instability and failure of the implants (Hansson & Halldin, 2007; Duyck & van Oosterwyck, 2014).

A number of finite element and clinical studies have highlighted that the implant prosthesis lacks the periodontal ligament, which makes it mechanically unfavorable to natural dentition in the face of load forces, which are then susceptible to load-induced movement and bone stress (Guichet et al., 2001; Zupan et al., 2009). These findings are supported by the current data, which quantify real-time micro-motion during functional conditions and show that deleterious lateral loading can be reduced by designing the occlusal with modifications that are flattering to cusp inclinations and increasing the area of contact. These findings correspond to the studies indicating that the higher the angles of the occlusal force vectors to the long axis of the implant, the more beneficial the load transfer, and as a result, the peri-implant bone homeostasis (Natali et al., 2006; Teo et al., 2013).

The clinical implications of this study are that the augmented micro-motion with parafunctional and unilateral loading conditions is a symptom of clinical complication concerns in implant dentistry (Manfredini et al., 2015; Louropoulou et al., 2020). Even though, in many clinical conditions, short implants show no significant differences in the survival rates as compared to longer ones, their shorter anchorage length and higher crown-to-implant ratios may increase the effect of bending moments during off-axis loading (Telleman et al., 2011; Andersson et al., 2018). The current results indicate that proper occlusal design might be able to eliminate these biomechanical drawbacks through modulating micro-motion, and, as a result, might decrease the probability of marginal bone erosion and prosthetic complications.

Dynamic 4D-CT imaging provided a novel method to measure the functional behavior of implants, as compared to the conventional methods of radiographic assessment, which cannot measure real-time motion at the time of loading. The past imaging research has extensively employed the use of a static or simulated loading condition, and this may not reflect the actual biomechanical nature of mastication and parafunction (Pigozzo et al., 2018; Ren et al., 2021). This research is more comprehensive in showing the effects of the oscillatory aspect of implant mobility in relation to the temporal aspect of micro-motions, which underlines the idea that the implant prosthetic planning must consider the occlusal aspects.

There are significant clinical implications of these findings. One of the most critical features of short implants with high-load conditions like the posterior mandible is that prosthetic occlusal schemes must be aimed at flattening cusp inclination, increasing occlusal contact area, and preventing premature contacts that cause lateral forces. These measures may be used to reduce micro-motion and facilitate biomechanical stability, which may ultimately enhance future outcomes. Although these are encouraging findings, longitudinal clinical trials should be conducted to confirm the findings of these biomechanical characteristics and to establish their impact on the survival of implants and preservation of bones around implants in the long term.

CONCLUSION

The results of this paper have shown that the geometry of occlusal schemes plays a strong role in the micro-motion of short dental implants positioned in the posterior mandible. These results were seen in the implants with steep cusp inclination, intense occlusal contacts, and poor distribution of loads, which demonstrated higher micro-movement and those with flatter occlusal design with well-distributed forces with better biomechanical stability. Dynamic 4D-CT was found to be a useful method to measure an implant under functional loading. Planning of occlusal and optimal geometry is the solution to improve the stability and long-term outcome of short implants in the posterior mandible.

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