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TO EVALUATE THE EFFECT OF CYCLIC LOADING ON THE SURFACE OF IMPLANT PROSTHETIC SCREW AT DIFFERENT TIME INTERVALS USING SEM IN- VITRO STUDY

Prosthodontics

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ABSTRACT

This is an in-vitro study which assess the impact of cyclic loading on the surface of implant prosthetic screws over different time intervals using Scanning Electron Microscopy (SEM). The research aims to understand wear patterns and morphological changes under mechanical stress, contributing to improved implant design and longevity. This prospective study aimed to investigate two key issues related to dental implants: screw loosening and screw fracture. 46 implants were included in this study. Cases are categorized into 2 distinct groups. Group I focused on addressing implant screw loosening, while Group II aimed to determine the maximum fracture load of implant screws. The results were statistically analyzed with a Paired t-test. The mean reverse torque value before cyclic loading found to be 27N-cm, while the mean value after cyclic loading is 23.84 N-cm. The reduction in mean reverse torque value from pre-cyclic to post-cyclic loading indicates that cyclic loading significantly diminishes reverse torque values. This finding highlights the impact of cyclic loading on the samples, demonstrating a notable change in their mechanical properties of implant prosthetic screw that is loosening of the prosthetic screw ($p< 0.05$). For the Group II samples the maximum compressive force at which the implant fractured was 2100 N, with a displacement rate of 3.2 mm/min. The mean compressive load was 1660.7 N, while the mean displacement rate was 1.996. This study demonstrates how cyclic loading affects implant prosthetic screws by examining changes in microstructure, surface morphology, and damage using SEM analysis. These findings underscore the need for vigilant monitoring in implant dentistry to prevent screw failure. The research informs clinical practice and aids in developing better materials and designs to enhance screw durability and longevity, ultimately improving patient outcomes in dental implant treatment.

KEYWORDS

Reverse torque value, Scanning electron microscope.

INTRODUCTION

Dental implants are highly effective for restoring function and aesthetics, particularly for individuals with partially edentulous jaws. Their use has evolved significantly, enhancing prosthodontic treatments. However, complications such as screw or abutment loosening, crown fractures, retention loss, abutment sinking, and fractures of fixtures or screws are common concerns for both clinicians and patients, often due to the properties and design of implant components[1].

The analysis of Maximum Bite Force (MBF) emphasizes the importance of patient comfort for accurate measurements, as discomfort can affect the willingness and cooperation of the subject[2]. Since the advent of osseointegrated implants by Branemark there has been a shift from solely focusing on bone integration to also understanding biomechanical interfaces and addressing mechanical failures, such as component loosening and fracture[3].

Ensuring the implant-abutment junction remains stable is crucial for the success of single-tooth prosthetics. Screw loosening remains a common issue, often caused by inadequate torquing during installation, structural deficiencies, and the complex forces acting on implants. This problem affects both patients, who experience discomfort and compromised functionality, and practitioners, who face challenges in ensuring the long-term success of restorations[4,5].

Fractographic analysis of implant failures provides insights into the diverse stress loads imposed on dental implants, revealing the mechanical forces at play during their operational lifespan. Understanding the mechanisms behind implant failures, which are often due to bacterial infections or occlusal overloads, is crucial for developing improved implant designs and treatment protocols. Enhanced maintenance and monitoring can mitigate these risks, ultimately improving implant longevity and reliability[6].

MATERIAL AND METHODS

This study was conducted at the Department of Prosthodontics & Crown and Bridge, NIMS Dental College, Jaipur. A study will be conducted between loosening and fracture surface morphology using 46 samples of conventional dental implants. Group I and Group II were designated for evaluating loosening and fracture of implant respectively and examining micro distortions on the implant surface through Scanning Electron Microscope (SEM).

Inclusion criteria:

1. Conventional implant with stock abutment.
2. Well Finished and polished crown fabrication.
3. The acrylic block in which the implant is mounted should have accurate dimensions so that it can fit securely into the fixture of the loading machine.

Exclusion criteria:

1. Presence of visible surface defects or damage unrelated to cyclic loading.
2. Any signs of contamination or interference that could obscure the assessment of cyclic loading effects.
3. Specimens showing evidence of prior mechanical stress or deformation.

Methodology

For this study, conventional implants with a standard platform internal hexagon design were selected. These implants were characterized by a tapered shape, possessing a diameter of 3.75mm and a length of 10mm. The choice of these specifications was deliberate, as they reflect common dimensions found in dental implantology and hold relevance to clinical scenarios encountered in practice.

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A total 46 implants of implants are categorized into two groups: Group I for addressing implant screw loosening, and Group II for implant screw fracture.

The implants were securely embedded within a heat-cured acrylic block, which served as a stable mounting platform for the subsequent testing procedures. The acrylic block measured 20mm in length and 11.2mm in diameter, providing ample support for the fixture-abutment assemblies during testing as shown in fig.1. Following the manufacturer's guidelines, all fixture-abutment assemblies were meticulously assembled, ensuring proper alignment and fit. To attain the advised level of tightness and stability, a torque setting ranging from 30 to 35 N-cm was utilized.

After securely mounting the implant within the acrylic block and completing the fabrication of the metallic crown, the crown was affixed to the abutment using Glass Ionomer Cement (GIC). This cementation process ensured a secure attachment between the crown and abutment, simulating clinical conditions where the crown is permanently fixed onto the implant.

After allowing the cement to fully set for 24 hours to ensure optimal bonding strength, the samples underwent testing in a cyclic loading machine. This machine applied controlled and repetitive loads to the samples, simulating the forces experienced during chewing and mastication. By subjecting the samples to cyclic loading, the study aimed to assess the durability and resilience of the implant- abutment-crown complex under realistic mechanical stresses, providing insights into its performance and potential areas for improvement.

Throughout the duration of the study, stringent measures were taken to ensure environmental stability, with the ambient temperature and relative humidity maintained at precise levels of 23.2°C and 50%, respectively. Strict adherence to these controlled conditions minimized the impact of external factors on the mechanical properties of the specimens, ensuring the reliability and reproducibility of the test results.

The dental implant sample is securely positioned within a specialized fixture for mechanical testing, as shown in the fig 2. This fixture ensures stability and provides a controlled environment for assessing the implant's mechanical properties, allowing accurate evaluation of its performance under simulated loading conditions.

Group I sample testing

Following crown cementation, abutment screw was initially tightened upto ≤35 N-cm using torque gauge, and then readjusted to 35 N-cm after allowing a ten minute settling period. Reported whole process was repeated for every 23 cases. Following a 5-minute wait, A digital torque meter was used to measure the pre-cyclic loading Reverse Torque Value (pre-RTV) for every case in Group I. The cases then underwent cyclic loading, simulating human masticatory forces of approximately 109 N, in a dry environment. Following loading, Reverse Torque Value for each case in Group I was reassessed using digital torque meter.

Group II sample testing

The Group II samples were prepared identically to Group I to ensure consistency. Each sample was fixed into the testing fixture and subjected to loading on a unidirectional vertical platform at a constant rate of 1 mm/min until its failure. Advanced computer systems recorded the maximum load at failure and generated force- versus-displacement curves for each sample, providing insights into the implants' mechanical behavior. Specimens that deformed or fractured were analyzed using a field emission scanning electron microscope (SEM).

Figure 1. Test Sample

Figure 2. Test Setup

Statistical analysis

The data were presented in both graphical and tabular forms. Descriptive statistics, such as mean and standard deviation, were calculated for every pre- and post-cyclic loading, compressive load, and displacement rate. Paired t-tests were used to assess the effect of loading, with a significance level set at 5% (Statistical significance was also determined with a p-value of < 0.05). Statistical analyses were conducted by SPSS and Microsoft Excel software.

RESULT

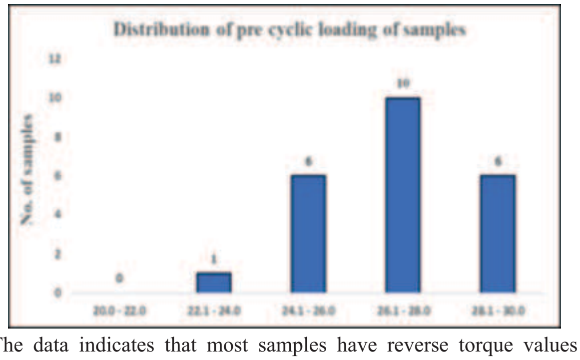
Group I Implant Prosthetic Screw Loosening

The study quantified both pre-cyclic loading reverse torque values (pre-RTV) and post-cyclic loading reverse torque values (post-RTV) using digital torque meter to assess loosening of implant prosthetic screw. Their frequency distributions are detailed in Table 1 and Table 2, correspondingly. The pre-cyclic loading (pre-RTV) maximum reverse torque values showed the highest frequency in 6 samples, ranging from 28.1 to 30.0 N-cm.

The lowest reverse torque value, between 22.1 and 24.0 N-cm, was observed in only one sample. The most common range was 26.1 to 28.0 N- cm, indicating that a significant portion of the samples had reverse torque values within this range (Table 1).

Table 1: Frequency distribution of pre cyclic loading

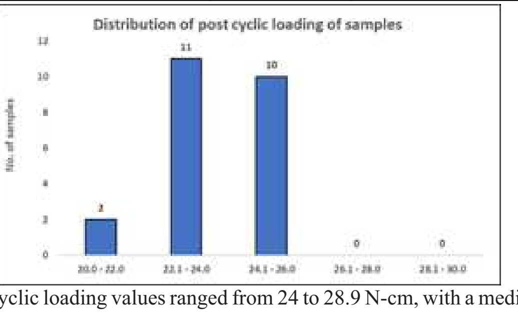
Pre cyclic Loading (pre- RTV) (N-cm)	n = 23	In %
20.0 - 22.0	0	0.00%
22.1 - 24.0	1	4.35%
24.1 - 26.0	6	26.09%
26.1 - 28.0	10	43.48%
28.1 - 30.0	6	26.09%



The data indicates that most samples have reverse torque values between 22.1 and 26.0 N-cm, with the 22.1 to 24.0 N-cm range being the most populated. No samples have reverse torque values higher than 26.0 N-cm, suggesting that the majority exhibit moderate reverse torque values after cyclic loading (Table 2).

Table 2: Frequency distribution of post cyclic loading

Post cyclic Loading	n = 23	In %
20.0 - 22.0	2	8.70%
22.1 - 24.0	11	47.83%
24.1 - 26.0	10	43.48%
26.1 - 28.0	0	0.00%
28.1 - 30.0	0	0.00%



Pre-cyclic loading values ranged from 24 to 28.9 N-cm, with a median of 27.6 N-cm, a mean of 27 N-cm, and a standard deviation of 1.45. Post-cyclic loading values decreased to 21.6 to 25.7 N-cm, with a median of 23.9 N-cm, a mean of 23.84 N-cm, and a lower standard deviation of 1.16. This indicates that cyclic loading decreases reverse torque values and results in a more consistent distribution (Table 3).

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Table 3: Descriptive statistics of pre and post cyclic loading

Group	Minimum	Maximum	Median (IQR)	Mean ± SD
Pre cyclic loading	24	28.9	27.6 (25.8-28.1)	27 ± 1.45
Post cyclic loading	21.6	25.7	23.9 (22.95-24.75)	23.84 ± 1.16

Analysis of pre and post cyclic loading was done using a paired t-test (Table 4), to assess significance of the difference. The mean reverse torque value of pre cyclic loading found to be 27 N-cm (SD = 1.45), while after cyclic loading, it was 23.84 N-cm (SD = 1.16). The test yielded a t-value of 8.598 and a p-value of 0.00001, showing significant statistically difference ($p < 0.05$). This p-value of 0.00001 indicates a strong difference in mean reverse torque values of pre and post cyclic loading. This decrease in mean reverse torque value suggests that cyclic loading substantially reduces reverse torque values, highlighting its impact on the mechanical properties of implant prosthetic screws, particularly in causing screw loosening.

Table 4: Comparing Pre And Post Cyclic Loading By Using Paired T-test

Group	Mean ± SD	Paired-t test	P - Value	Significance
Pre cyclic loading	27 ± 1.45	8.598	0.00001	Significant
Post cyclic loading	23.84 ± 1.16			

The data indicates a balanced distribution of compressive load values from 1200 to 2000 N, with the highest concentration of samples in the 1601 to 1800 N range, suggesting most samples experience moderate compressive loads. Higher compressive loads between 2001 and 2200 N are less common, as evidenced by fewer samples in this range. This pattern shows that most compressive load values are centered around the mid-range, with few instances of extreme values.

Table 5: Frequency distribution of compressive load

Compressive Load	n = 23	In %
1200 - 1400	5	21.74%
1401 - 1600	5	21.74%
1601 - 1800	6	26.09%
1801 - 2000	5	21.74%
2001 - 2200	2	8.70%

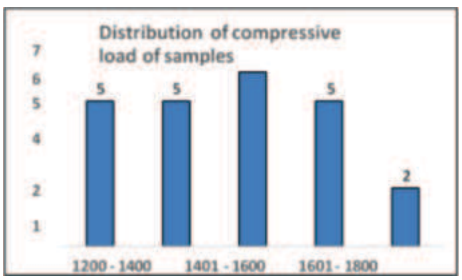
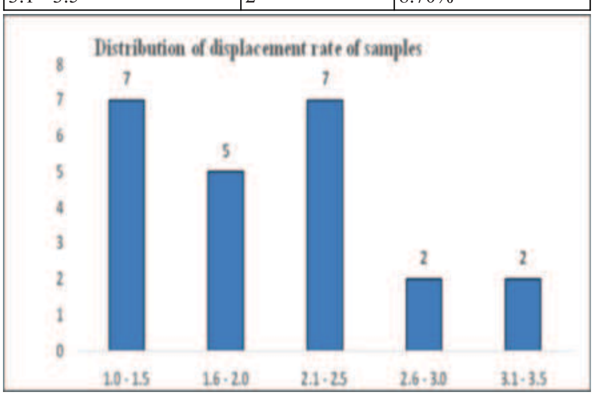


Table 6: Frequency Distribution Of Displacement Rate

Displacement Rate	n = 23	In %
1.0 - 1.5	7	30.43%
1.6 - 2.0	5	21.74%
2.1 - 2.5	7	30.43%
2.6 - 3.0	2	8.70%
3.1 - 3.5	2	8.70%



The data shows that displacement rates of 1.0 to 1.5 and 2.1 to 2.5 are the most frequent, each accounting for 30.43% of the total sample size. The 1.6 to 2.0 range also has a moderate frequency. In contrast, the 2.6 to 3.0 and 3.1 to 3.5 ranges have lower frequencies, indicating that higher displacement rates are less common in the sample set.

Table 7: Descriptive Statistics Of Compressive Load And Displacement Rate

Variables	Minimum	Maximum	Median (IQR)	Mean ± SD
Compressive Load	1220	2100	1675 (1450-1837.5)	1660.7 ± 260.6
Displacement Rate	1	3.2	2 (1.45-2.3)	1.996 ± 0.672

The result chart presents the descriptive statistics of compressive load and displacement rate for the implant prosthetic screw. The maximum compressive force at which the implant fractured was 2100 N, with a displacement rate of 3.2. The mean compressive load was 1660.7 N with a standard deviation of 260.6, and the mean displacement rate was 1.996 with a standard deviation of 0.672, indicating relatively consistent values across the samples.

Scanning Electron Microscope (SEM) Analysis

SEM plays a crucial role in understanding implant prosthetic screw behavior under loading conditions, providing high-resolution images for detailed analysis and interpretation. This study observed changes in implant prosthetic screws after applying loads between 1220-2100N as shown in fig. 3. Fig. 4 shows the abutment screw head with visible stripping (red arrow). Fig.5 depicts the screw shank, extending from the underside of the head to the initial thread, where bending was observed on both the outer surface and the thread-shank junction. Figures 6 and 7 illustrate thread distortion at the junction of the shank and the first thread, a common fracture site. These insights contribute to improving implant outcomes and patient care in implant dentistry.

Figure 3. Distorted Implant Prosthetic Screw

Figure 4. SEM Of Head Of The Screw

Figure 5. SEM Of Shank Of The Screw

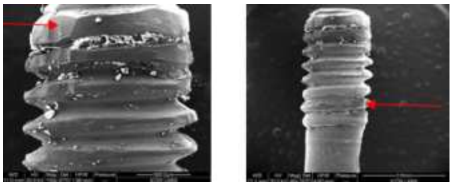


Figure 6 & 7 SEM Of Threads Of The Screw

DISCUSSION

Implant-supported prostheses are a well-established treatment for missing teeth, known for their high success rates and versatility. Two-piece dental implants are preferred over single-piece systems due to their adaptability across various clinical scenarios[7,8]. McGlumphy et al. describe a screw joint comprising of abutment and an implant fastened to each other by screw. Applying torque causes the screw to elongate, generating preload that creates clamping force essential for joint integrity. Screw loosening happens when separating forces surpass this clamping force, resulting in decreased preload.[9,10,11].

Factors such as applied torque, screw material, head design, and abutment surface. Influence preload, which can be consistently reproduced across implant prostheses. Inadequate torque can lead to joint separation and screw fatigue, while excessive torque can strip the screw threads[9]. This study used conventional implants with stock abutments for mechanical testing. Abutment screws were tightened to 35 N-cm, and cyclic loading significantly reduced reverse torque values, indicating screw loosening.

Sammour SR et al.[12] found that conical hybrid connection provides better stability in screws than using internal hex connections. This study measured pre- and post-reverse torque values, showing a decrease post cyclic loading, indicating the effect of loading on screw stability[13]. Attiah EMN et al. found that retightening screws in both narrow and standard implants is more effective than using new screws[14]. Ahmed SE et al. observed less screw

loosening in premachined titanium abutments compared to custom cast cobalt-chromium abutments[7]. Preload loss during occlusal loading can compromise the implant-abutment connection, leading to mechanical failure and biological complications. Solutions include centering occlusal contact and applying correct torque[10,11,15].

In a study by Yona KS et al[16], implants with a diameter of 3.6mm and length of 11.5mm were subjected to randomly varying loads. Ten implants were tested at room temperature, while another ten were tested in a 0.9% saline solution. The results revealed that the dry implants failed after an average of 3432±1515 N, whereas those tested in the saline solution sustained an average of 2266±695 N before failure. This indicates a significant reduction in the lifespan of implants when exposed to saline solution.

Sung-Woon On's[17] study compared three implant systems: BLX (control group), TORX ++(test group 1), and IU (test group 2). Each group had three samples subjected to static compression tests to determine maximum fracture load. The mean maximum breaking loads were determined as follows: 578.45 ± 42.46 N for the BLX implant, 793.26 ± 57.43 N for the TORX++ implant, and 862.30 ± 74.25 N for the IU implant.

SEM analysis in this study revealed patterns of screw distortion, including stripping, bending, and thread distortion. Studies by Vinhas AS et al[18]. demonstrated increased damage and deformation with multiple tightening and cyclic loading. Significant preload loss post-loading indicated abutment screw loosening. Future research should explore variables like eccentric forces, angulated abutments, increased compressive forces, and different materials to enhance implant stability.

CONCLUSION

This study provides valuable insights into the effects of cyclic loading on implant prosthetic screws through SEM analysis conducted at various time intervals. The observed changes in microstructure, surface morphology, and signs of damage highlight the dynamic nature of screw under mechanical stress. These findings emphasize the importance of vigilant monitoring and maintenance in implant dentistry to mitigate the risk of screw failure. By elucidating the mechanisms underlying screw damage, this research informs clinical practice and facilitates the development of preventive measures and alternative materials designs to enhance the longevity and durability of implant prosthetic screws. Moving forward, continued research in this area will contribute to further advancements in implant prosthodontics, ultimately improving patient outcomes and satisfaction in dental implant treatment

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