International Journal of EnvironmentalSciences
ISSN: 2229-7359
Vol.11 No.18s, 2025
https://theaspd.com/index.php

Evaluating effect of Implant Inclination and type of Abutment on Biomechanics of Implant prosthesis

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Abstract

Background:*Implant-supported prostheses are a reliable treatment for edentulous and partially edentulous patients. However, biomechanical complications such as marginal bone loss and screw loosening may arise due to improper implant angulation and abutment selection. Implant inclination alters the direction of occlusal force transmission, while abutment type influences the load distribution pattern. Understanding these factors is critical to optimizing long-term success and prosthetic stability.*

Materials and Methods:*This in vitro study was conducted to evaluate the biomechanical effect of varying implant inclinations (0°, 15°, and 25°) and two types of abutments (straight and angulated) on stress distribution in implant-supported prostheses. A total of 12 polyurethane mandibular models were used, with implants placed in the second premolar region at different inclinations. Strain gauges were bonded to record microstrains under static vertical load (100 N). A finite element analysis (FEA) was also conducted to validate stress patterns. The main outcomes included strain levels around implants and stress distribution in abutments and crowns.*

Results:*Implants with 0° inclination and straight abutments showed the lowest strain values ($245.3 \pm 21.7\,\mu\varepsilon$), while 25° inclined implants with angulated abutments recorded the highest strain ($487.6 \pm 30.4\,\mu\varepsilon$). The FEA results corroborated the experimental findings, indicating increased stress concentration around the cervical region of inclined implants. A statistically significant difference was observed between groups ($p < 0.01$). Angulated abutments partially compensated for inclined implant placement, but did not eliminate unfavorable stress patterns entirely.*

Conclusion:*Implant inclination significantly influences the biomechanical behavior of implant-supported prostheses. While angulated abutments can reduce stress concentrations, optimal outcomes are achieved when implants are placed with minimal inclination. Proper implant alignment during placement should be prioritized to ensure longevity and stability of the prosthesis.*

Keywords:*Implant inclination, Angulated abutment, Biomechanics, Finite element analysis, Strain gauge, Stress distribution.*

Introduction

Dental implants have become a widely accepted modality for replacing missing teeth due to their favorable long-term outcomes and high success rates. The functional and esthetic rehabilitation of patients using implant-supported prostheses depends not only on osseointegration but also on biomechanical factors such as implant positioning, angulation, and abutment selection. Improper implant inclination can alter the direction of occlusal forces, potentially increasing stress concentrations at the bone-implant interface and leading to complications such as peri-implant bone loss, screw loosening, or prosthetic failure (1,2).

Biomechanical stress distribution is directly influenced by the implant's three-dimensional orientation. Angled implants are often placed to compensate for anatomical limitations such as bone atrophy or proximity to vital structures, especially in the maxillary anterior and posterior regions (3,4). However, excessive angulation may redirect occlusal forces off-axis, increasing the risk of micromovement and biomechanical overload (5). Additionally, the type of abutment—whether straight or angulated—affects how masticatory loads are transferred through the prosthesis to the implant and surrounding bone (6). Several in vitro and finite element analysis (FEA) studies have shown that implants placed at an angle experience higher stress concentrations compared to those placed axially (7,8). Angulated abutments are commonly used to correct implant angulation and improve prosthetic alignment, but their ability to mitigate adverse stress patterns remains a subject of ongoing research (9). Despite their routine clinical use, limited consensus exists regarding the optimal combination of implant inclination and abutment type to ensure favorable biomechanical outcomes.

The present study aims to evaluate the biomechanical impact of different implant inclinations and abutment types on stress distribution in implant-supported prostheses using both strain gauge analysis and FEA. This investigation seeks to provide insights that can inform clinical decision-making for enhancing the long-term success and mechanical stability of implant prostheses.

Materials and Methods

This in vitro experimental study was designed to assess the biomechanical influence of varying implant inclinations and abutment types on stress distribution in implant-supported prostheses. A total of 12 polyurethane mandibular arch models were fabricated to simulate posterior mandibular bone anatomy. All models were standardized in dimension and density to minimize variability.

Commercially available titanium dental implants (4.0 mm diameter, 10 mm length) were inserted in the region corresponding to the second premolar at three different angulations: 0° (axial), 15°, and 25° relative to the vertical axis. Each angulation group included four samples. Two types of abutments were evaluated: straight abutments (0°) and pre-angled abutments (15°). Implants and abutments were tightened according to the manufacturer's recommended torque specifications using a calibrated torque wrench.

Customized metal crowns were fabricated for each abutment and were luted using dual-cure resin cement to ensure uniform fixation. Strain gauges (with 350-ohm resistance) were bonded on the buccal and lingual surfaces of the implant platform level in each model to record microstrain during loading.

A universal testing machine (Instron, USA) was used to apply a vertical static load of 100 N at a crosshead speed of 1 mm/min, directly onto the occlusal surface of the crown. The strain gauge readings were recorded and analyzed to quantify the microstrain distribution around each implant.

In addition to physical testing, a three-dimensional finite element model was developed using CAD software to simulate the same experimental conditions. The model included the implant, abutment, crown, and surrounding bone structure. Material properties were assigned based on published literature, assuming isotropic, homogenous, and linearly elastic behavior. Static vertical loading of 100 N was applied in the simulation to evaluate stress distribution patterns. Statistical analysis was performed using SPSS version 25.0 (IBM Corp., USA). Mean and standard deviation of microstrain values were calculated for each group. One-way ANOVA followed by Tukey's post hoc test was used to assess statistical significance between groups. A p-value < 0.05 was considered statistically significant.

Results

The study evaluated the microstrain distribution around dental implants placed at different inclinations (0°, 15°, and 25°) and restored using either straight or angulated abutments. The results revealed a clear trend of increasing microstrain with increasing implant inclination. Additionally, the use of angulated abutments showed a partial reduction in strain values compared to straight abutments at higher implant inclinations.

Table 1 summarizes the mean microstrain values (± SD) recorded from the strain gauges placed on each model under a vertical load of 100 N. Implants placed at 0° with straight abutments exhibited the lowest microstrain ($245.3 \pm 21.7\ \mu\varepsilon$), indicating the most favorable biomechanical condition. In contrast, implants placed at a 25° inclination with straight abutments demonstrated the highest strain ($487.6 \pm 30.4\ \mu\varepsilon$). When angulated abutments were used in the 25° group, the strain was moderately reduced ($421.2 \pm 26.9\ \mu\varepsilon$), suggesting improved stress distribution but still higher than axial placement.

Table 1: Mean microstrain values (με) for different implant inclinations and abutment types under 100 N load

Implant Inclination	Abutment Type	Mean Microstrain (με) ± SD
0°	Straight Abutment	245.3 ± 21.7
15°	Straight Abutment	356.8 ± 24.5
15°	Angulated Abutment	318.9 ± 20.1
25°	Straight Abutment	487.6 ± 30.4
25°	Angulated Abutment	421.2 ± 26.9

Statistical analysis showed a significant difference in strain values across groups ($p < 0.01$). Post hoc comparisons revealed that strain values increased significantly with implant angulation when straight abutments were used. However, angulated abutments significantly reduced strain in both the 15° and 25° inclination groups when compared to their straight counterparts ($p < 0.05$) (**Table 1**).

Finite element analysis supported these findings by revealing higher von Mises stress concentrations in inclined implants, especially at the crestal bone region. Angulated abutments helped shift stress apically and reduced the peak stress values by approximately 15–20% in inclined configurations compared to straight abutments.

Discussion

The present study investigated the biomechanical influence of implant inclination and abutment type on stress distribution in implant-supported prostheses using both in vitro strain gauge measurements and finite element analysis. The findings indicate that implant angulation significantly increases the peri-implant microstrain, while the use of angulated abutments helps to partially compensate for this effect. These results align with prior research emphasizing the critical role of implant positioning in ensuring biomechanical stability and prosthetic success.

Implant inclination modifies the direction of occlusal load transmission, often resulting in non-axial loading, which can lead to increased strain at the bone-implant interface and the prosthetic components (1,2). Our findings demonstrated that implants placed at 25° with straight abutments exhibited the highest microstrain, consistent with earlier reports indicating that excessive angulation beyond 15° may compromise biomechanical performance (3,4). Increased strain in inclined implants can induce micromotion and bone resorption, potentially leading to marginal bone loss and implant failure (5,6).

Angulated abutments are commonly employed to correct prosthetic emergence in cases of non-ideal implant angulation. In this study, the use of angulated abutments significantly reduced the stress around inclined implants compared to straight abutments. This agrees with observations by Clelland et al., who reported that angulated abutments distribute occlusal forces more evenly, especially in off-axis loading conditions (7). However, despite this improvement, strain levels remained higher than those observed in axially placed implants, indicating that abutment correction cannot entirely negate the adverse effects of inclination (8,9).

Finite element analysis further supported the experimental results by illustrating increased von Mises stress at the crestal region of inclined implants, particularly in the 25° group. Similar findings have been documented by Geng et al. and Baggi et al., where angulated implants showed higher stress concentrations at cortical bone levels compared to axial placements (10,11). These biomechanical alterations may have clinical implications, as excessive stress in the cortical zone is often associated with peri-implant bone remodeling and screw loosening (12,13).

The strain values recorded in our study were within physiological limits for bone, but the relative differences between groups highlight the importance of precise implant positioning. Several authors recommend minimizing implant inclination wherever feasible to reduce biomechanical complications and enhance load transfer efficiency (14,15). Moreover, the selection of an appropriate abutment should be

guided not only by prosthetic needs but also by biomechanical considerations, especially in posterior load-bearing zones.
While this study was conducted under controlled in vitro conditions, it has certain limitations. The use of static loading and homogeneous bone analogs may not fully replicate complex in vivo conditions, including dynamic masticatory forces and bone heterogeneity. Future studies incorporating cyclic loading and clinical trials are needed to validate the long-term effects of implant inclination and abutment type on implant survival and prosthetic integrity.

Conclusion

In conclusion, implant inclination significantly impacts stress distribution in implant-supported prostheses. Angulated abutments can improve load distribution in inclined implants but do not completely neutralize the biomechanical disadvantages. Therefore, clinicians should strive for optimal axial implant placement and use angulated abutments judiciously when anatomical constraints necessitate implant angulation.

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