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Research Article

Evaluation of Influence of Final Preload on Screw Stress and Formation of Implant-Abutment Micro Gaps Between Conical and Trilobe Connections: A Finite Element Analysis

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Abstract

Aim of Study: Evaluation of influence of final preload on screw stress and formation of implant-abutment micro gaps between conical and tri-lobe connections: a finite element analysis.

Materials: 1. Titanium implant data of Noble replace and Noble replace select from Noble Biocare implant system 2. Noble biocare torque wrench, 3. Noble biocare hex 4. Acrylic resin material 5. Load adapters for conical connection and trichannel connection 6. 3-D Finite element models implant and abutment embeded in resin with load adapter. Personal computer configurations • Hard disc: 500 Gigabyte. • Ram: 16 Gigabyte. Software configurations • Modeling – Solid Edge V19. • Meshing – Hypermesh V11. • Analysis – Ansys V18.1.

Methodology: In the present study, virtual models of implant-abutment connections with conical (Nobel Biocare Replace) and trichannel designs (Nobel Biocare Replace select) were created based on physical models. For these models, final preload values of 35 Ncm and 43.75 ncm were applied, and the tensile and compressive stresses at the abutment screw together the conical and trichannel models were recorded. An oblique stress was imposed to the models, and stresses were measured before, during, and after loading. These stress measurements, together with the evaluation of microgaps, were used to analyze how the conical and trichannel connections performs using specific software tools.

Result: 1. The conical implant–abutment connection demonstrated superior mechanical performance, with more favorable stress distribution and lower overall microgap values when compared to the trilobe implant–abutment connection. 2. The trilobe implant–abutment connection exhibited higher stress concentrations, particularly in the abutment screw and contact interface regions, potentially leading to increased mechanical complications such as screw loosening or fracture.

Keywords: Microgap; Finite Element Analysis (FEA); Screw Stress

Introduction

A dental implant abutment is a component that connects the dental implant to the crown or bridge, which replaces the missing tooth. The abutment is screwed onto the implant and provides a platform for the restoration to be attached. This connection must with stand various mechanical loads over time, including masticatory forces, without significant deformation or micro-movement that could lead to complications such as screw loosening, fracture, or bacterial infiltration. A common problem associated with the prosthetic application of dental implants is abutment screw loosening which is due to the "loss of preload" [1].

Internal connections have a greater potential for obtaining a microbial seal [2] between the abutment and implant than external connections. The abutment is mechanically linked to the implant's surface and must remain in place for the duration of the implant's life to avoid issues. For the prosthesis to function properly, keeping the implant and abutment relationship stable is crucial. The design, fit accuracy, materials utilized, screw geometry, degree of friction, preload, and abutment shape are just some of the numerous factors that influence the stability of the implant–abutment junction [3,4].

Finite Element Analysis (FEA) is a mathematical modeling technique used to address complex physical problems by segmenting them into smaller, more manageable finite elements. It has become a powerful technique for representing intricate structures and analyzing their mechanical properties. FEA is widely accepted as a non-invasive tool for studying biomechanics and the effects of mechanical forces on biological systems. It enables visualization of overlaid structures and allows specification of material properties in anatomical craniofacial structures. Additionally, FEA can pinpoint the location, magnitude, and direction of applied forces, as well as identify stress points that can be theoretically measured. Importantly, FEA does not alter the physical properties of the materials being analyzed, making the process easily repeatable. The null hypothesis states that no significant difference exists between the two connection types.

Materials and Methodology

Titanium implant data of Noble replace and Noble replace select from Noble Biocare implant system, Noble biocare torque wrench, Noble biocare hex ,Acrylic resin material ,Load adapters for conical connection and trichannel connection ,3-D Finite element models implant and abutment embeded in resin with load adapter.

- **Personal computer configurations:** Hard disc: 500 Gigabyte, Ram: 16 Gigabyte.
- **Software configurations:** Modeling – Solid Edge V19,Meshing – Hypermesh V11,Analysis – Ansys V18.1.

In the present study, virtual models of implant-abutment connections with conical (Nobel Biocare Replace) and trichannel designs (Nobel Biocare Replace select) were created based on physical models. For these models, final preload values of 35 Ncm and 43.75 Ncm were applied, and the tensile and compressive stresses at the abutment screw together the conical and trichannel models were recorded. An oblique stress was imposed to the models, and stresses were measured before, during, and after loading. These stress measurements, together with the evaluation of micogaps, were used to analyze how the conical and trichannel connections performs using specific software tools.

Figure 1: Conical Implant (Noble replace).

Figure 2: Trichannel Implant (Noble replace select).

A geometric model of the bone segment was constructed on a computer to generate a numerical representation. The bone segment consists of cortical and cancellous (spongy) bone. A 3D geometric model of the Nobel Biocare Replace conical connection was designed using implant-specific dimensions of 4.3 mm in diameter and 11.5 mm in length. The data were obtained from the manufacturer's existing model and recreated using specialized modeling software, Solid Edge V19. A 3D geometric model of the Nobel Biocare Replace select trichannel connection was designed using implant-specific dimensions of 4.3 mm in diameter and 11.5 mm in length. The data were obtained from the manufacturer's existing model and recreated using specialized modeling software, Solid Edge V19. A 3D geometric model of the Nobel Biocare straight conical abutment was created and integrated with the implant model. A 3D geometric model of the Nobel Biocare straight trilobed abutment was created and integrated with the implant model. A 3D geometric model of the crown was developed and subsequently integrated with the implant model to facilitate load application.

Figure 3: Conical implant embedded in acrylic material , conical and abutment screw.

Figure 4: Trichannel implant embedded in acrylic material , conical and abutment screw.

In this research, static oblique loads were imposed to the implant–abutment assemblies. The load magnitude was progressively increased from 0 N to 100 N in 10 N increments, and subsequently from 100 N to 280 N in 20 N increments to simulate functional masticatory forces. The components designed and modeled through finite element modeling included the Nobel Biocare conical and trichannel implant systems, each with dimensions of 4.3 mm in diameter and 11.5 mm in length. These assemblies consisted of the implant, straight abutment, abutment screw, and a crown-like load adapter representing the prosthetic component. Each model was developed and assembled in a simulated bone block comprising both cortical and cancellous bone.

Figure 5: Three-dimensional view of molar region (Cortical and cancellous bone).

After mesh generation and assignment of material properties, the models were subjected to static oblique loads to simulate functional masticatory forces. Preload torque values of 35 Ncm and 43.75 ncm were applied to the abutment screws to represent clinically relevant and elevated tightening scenarios. The loading protocol consisted of the application of oblique static loads: • From 0 N

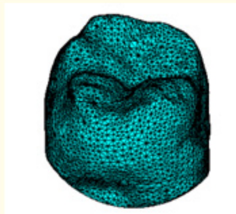

Figure 6: Crown Mesh.

to 100 N, in 10 N increments • From 100 N to 280 N, in 20 N increments These loads were applied at a 45° angle to the long axis of the implant through the load adapter, mimicking oblique masticatory force conditions typically encountered in the posterior maxillary region.

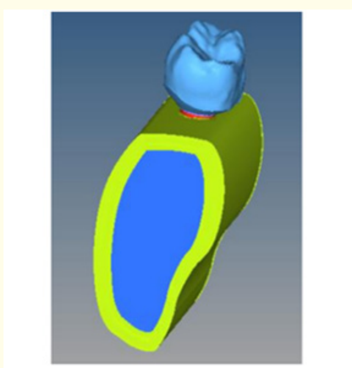

Figure 7: Geometric view of the problem.

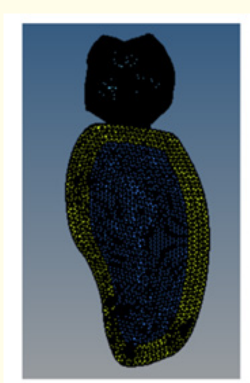

Figure 8: Mesh view of the problem.

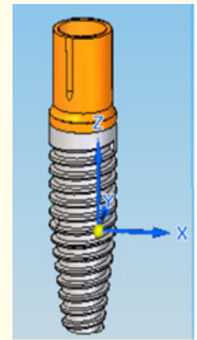

Figure 9: Noble Replace Select model (both implant and abutment).

Stress distribution in the abutment screw and implant–abutment interface was evaluated using ANSYS V18.1. The analysis focused on: • Tensile and compressive stresses • Von Mises stress distribution • Formation and variation of microgaps at the implant–abutment interface.

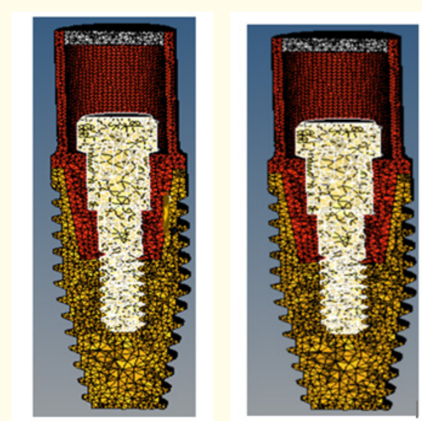

Figure 10: Sectional view of the implant with tri-channel connection.

Results

Finite element analysis revealed distinct mechanical behavior between the conical and tri-channel implant–abutment connections under different preload torques (35 Ncm and 43.75 Ncm).

For the Conical connection (Nobel Replace), stress at the implant–abutment intersection increased significantly from 23.23 to 30.79 MPa ($p < 0.05$) as torque rose, and the microgap widened from 0.00137 mm to 0.00167 mm ($p < 0.05$).

For the Tri-channel connection (Nobel Replace Select), abutment screw stress rose from 10.01 to 30.75 MPa ($p < 0.05$), intersection stress from 24.59 to 31.62 MPa ($p < 0.05$), and microgap from 0.00138 mm to 0.00178 mm ($p < 0.05$). Thus, both stress and microgap increased significantly beyond the recommended torque.

At 35 Ncm, the Tri-channel system showed slightly higher screw stress (10.01 vs 9.84 MPa, $p < 0.05$), with no significant difference in intersection stress or microgap ($p > 0.05$). At 43.75 Ncm, abutment screw stress was significantly higher in the Tri-channel (30.75 MPa) than in the Conical (12.43 MPa) ($p < 0.05$), while intersection stress was comparable ($p > 0.05$). The Tri-channel also showed larger microgaps (0.00178 vs 0.00167 mm, $p < 0.05$).

Strong positive correlations were found between torque and screw stress for both designs ($r = 0.987–0.996$, $p < 0.05$). Line and scatter plots confirmed increasing stress with higher torque across compressive and tensile loading cycles (0–280 N).

Overall, the Conical connection at 35 Ncm presented the most favorable stress distribution and minimal microgap, while excessive torque (43.75 Ncm) significantly elevated stress and microgap formation, especially in the Tri-channel system.

Discussion

The present research evaluates the effect of preload torque on mechanical stress distribution and microgap formation under oblique loading for two Nobel Biocare internal implant–abutment connections: Conical (Nobel Replace) and Tri-channel (Nobel Replace Select). Preloads of 35 Ncm (recommended) and 43.75 Ncm (25% higher) were compared. Finite Element Analysis (FEA) simulated two connection geometries subjected to oblique loading, with Von Mises stress used to assess stress concentrations and microgap development (Tonin., *et al*. [5], Caricasulo., *et al*. [6], Shetty., *et al*. [7], Balik., *et al*. [8], Larrucea., *et al*. [9], Sagheb., *et al*. [10], Satpathy., *et al*. [11], Sammour., *et al*. [12], Lang., *et al*. [13]).

Results show that preload significantly influences stress distribution and microgap formation; its effects vary by connection design. The conical interface displayed optimal biomechanical behavior at 35 Ncm, with reduced stress levels and minimal microgap formation, supporting the use of moderate torque in tapered systems (Tonin., *et al*. [15]). In tri-channel connections, higher preload led to increased localized stress and larger microgap values under oblique cyclic loading, while 35 Ncm yielded more favorable interface stability (Sammour., *et al*. [8], Lee., *et al*. [10]). Across 280 loading cycles, all configurations demonstrated gradual tensile stress reduction, indicating mechanical relaxation and improved adaptation at the interface (Lee., *et al*. [10]).

Microgap formation was lowest and most stable in the conical 35 Ncm group, while tri-channel connections performed best for compressive oblique loads at the same preload (Sahin and Ayyildiz [19]). These findings demonstrate the importance of optimizing torque to each connection geometry. Excessive preload does not consistently reduce microgaps and may increase stress, especially in non-tapered designs (Macedo., *et al*. [12]). Moderate preload enhances joint stability and minimizes clinical complications (Tribst., *et al*. [16]).

This study emphasizes the need to tailor torque strategies to connection type, optimizing biomechanical outcomes and supporting long-term implant success (Satpathy., *et al*. [7]).

Summary and Conclusion

The study concludes

- The null hypothesis was rejected, showing significant differences in screw stress distribution and microgap formation between conical and trilobe connections under different preload conditions.
- The conical connection demonstrated superior mechanical performance with more uniform stress distribution and lower microgap values.

- The trilobe connection showed higher stress concentrations at the abutment screw and interface, increasing the risk of mechanical complications.
- Increasing the final preload torque led to greater micro-gap formation in both connection types, especially under oblique loading.
- Excessive preload induced stress-related deformation at the interface, resulting in microgap enlargement rather than improved sealing.
- The conical design exhibited smaller and more stable microgaps, while the trilobe design displayed larger and more variable gaps with torque increase.
- Optimal preload application is critical; excessive torque can be counterproductive, particularly for trilobe systems.
- Clinically, conical implant–abutment connections are preferable for enhanced mechanical engagement, sealing integrity, and long-term biological stability.

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