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How to cite

COVANI, Ugo et al. An evaluation of new designs in implant-abutment connections: a finite element method assessment. In: Implant Dentistry, 2013, vol. 22, n° 3, p. 263–267. doi: 10.1097/ID.0b013e318292625f

This publication URL: https://archive-ouverte.unige.ch/unige:111704
Publication DOI: 10.1097/ID.0b013e318292625f

An Evaluation of New Designs in Implant-Abutment Connections: A Finite Element Method Assessment

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Purpose: *This research sought first to evaluate the differences in the finite element method (FEM) analysis of 4 different implant surfaces, including internal and external connections of the same manufacturer with additional modifications.*

Methods: *In this study, 4 dental implants from the same manufacturer were compared. A connection system was modified with a collar to improve its stability. A nonlinear dynamic analysis by FEM was used to calculate the transient response of the dental implant systems.*

Results: *The results of FEM analysis indicated that the implant-modified configuration is more efficient in loading support when compared with the others.*

Conclusion: *In the present research, 4 different types of connections were evaluated: a modified internal hex connection with a collar (to increase stability), an internal hex connection, a standard connection without hex, and an external connection. These data demonstrated that the internal hex connection with the modification of the manufacturer's original is much more resistant to loosening and/or distortion than the traditional hex. (Implant Dent 2013;22:263–267)*

Key Words: implant connections, stress loading, mechanic analysis

The fundamental criterion for evaluating the success of a dental implant is the achievement of an ankylotic anchorage of the titanium implant with the jawbone, a process known as "osseointegration."[1–3] However, some studies have shown that these dental implants may have several complications, especially after the conclusion of the prosthetic phase.[4] The major causes of implant failure are as follows: deficient osseointegration, complication of the neighboring soft tissues, and mechanical complications.[4,5] Researches have focused on the causes of implant failure by investigating implant surfaces and evaluating the problem of peri-implantitis to increase their success rate.[5] Simon[6] determined the success rate of implants restored as single molar and premolar crowns and reported that the implant failure rate was 4.6%. This research stressed that abutment screw loosening occurred in 7% of such failed implants, suggesting that the implant-abutment connection can play a role in determining consequent implant failure.[6]

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ISSN 1056-6163/13/02203-263
Implant Dentistry
Volume 22 • Number 3

DOI: 10.1097/ID.0b013e318292625f

Therefore, most research has been directed at the biomechanical problems, which include screw loosening, abutment rotation, and abutment fracture.[7,8] Henry et al[9] observed in a group of 107 implants that the problems most frequently experienced during the first year were related to loose screws. It has been demonstrated that screw loosening may be due to excessive bending, which happens when a load greater than the yield strength of the screw is applied, or screw settling, when external loads applied to the screw interface create micromotion between both surfaces.[7] Moreover, there are several factors that contribute to screw instability, such as misfit of the prosthesis, insufficient tightening force, mechanical overload, and mismatch in screw material and design.[10]

In recent years, manufacturers have developed various implant-abutment connection designs. These can be roughly divided into 2 main groups: the first may be described as butt joints or slip-fit joints, with a passive connection and a slight space between the implant and abutment,[11] whereas the second includes conical interface designs with friction fit joints.[12] Both of them can be divided into external and internal connection types. In the internal connection types, connective parts of the abutment are placed into the implant body. In contrast, an external connection type is observed when connective parts of the abutment enclose an extension of the implant body. Various studies have been carried out to compare the efficacy of different connecting systems securing the abutment to the implant platform.[13] The stability of an implant-retained prosthesis depends on the integrity of the screw connection.[9] Yousef et al[14] reported that off-axis loading may result in screw and abutment deformation with subsequent screw loosening. Implants featuring a short external hexagon at the prospective connection with the abutment seem to be especially prone to screw loosening. Some authors reported a high incidence of screw loosening for the external abutment connections,[15,16] although the external implant-abutment connection and the internal implant-abutment connection use different mechanical principles of function. In the external connection, the axial preload of the abutment screw is the determining factor for stability of the connection.[13] However, for the internal connections, internal form fit is the basic mechanical principle and lateral loading is resisted by the frictional interface.[13]

The use of clinical studies to evaluate the success of an implant connection is not ideal and presents major drawbacks. In fact, they are time-consuming, expensive, and they do not allow for an evaluation of the stress using a systematic approach. To overcome these limits, the finite element method (FEM) was introduced. This is a powerful and effective tool for predicting the mechanical behavior of dental restorations,[17] fixed partial dentures,[18] and implant-supported prostheses.[19] The mechanical behavior of dental implant systems, such as hydroxyapatite-coated implants and implants with stress adsorbing elements, have already been investigated using this technique.[20]

In recent years, many modifications have been proposed by manufacturers to improve mechanical stability. With this in mind, our research sought first to evaluate the differences in the FEM analysis of 4 different implant surfaces, including internal and external connections of the same manufacturer with additional modifications. The second aim was to evaluate the maximum load that the best type of connection could tolerate during a fatigue test.

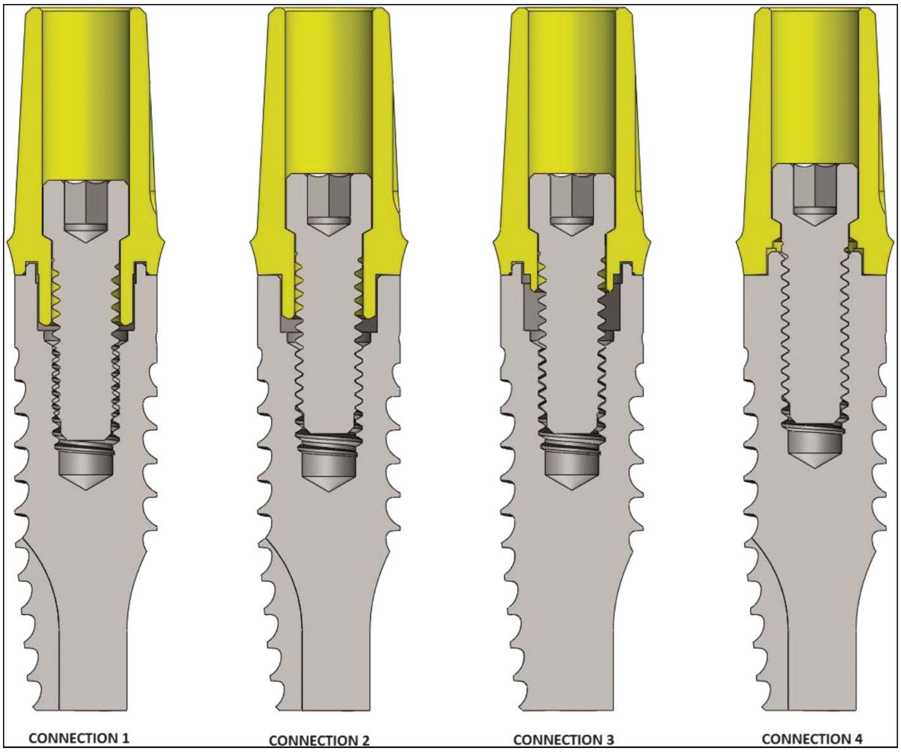


Fig. 1. Different types of abutment-implant connections involved in this research (left to right)—Premium implant (Sweden Martina), implant 1: the connection is made with an internal hexagon with a small collar, which was invented to distribute the load on all the implant surface and to provide for greater stability. Premium implant (Sweden Martina), implant 2: internal hexagon connection without a collar. Premium implant (Sweden Martina), implant 3: internal connection without hexagon. Premium implant (Sweden Martina), implant 4: external hexagon connection.

MATERIALS AND METHODS

In this study, 4 dental implants from the same manufacturer were compared:

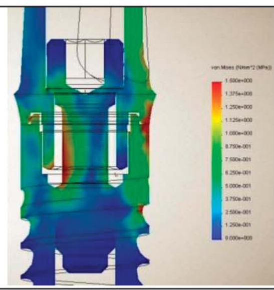
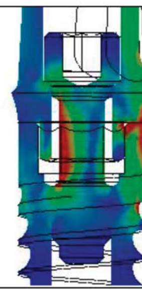
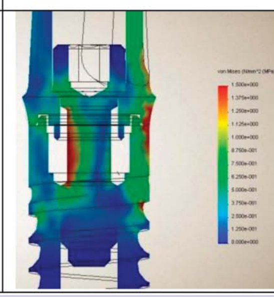
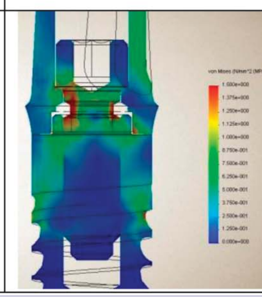
- Premium implant (Sweden Martina, Padova, Italy)—Implant 1: The connection is made with an internal hexagon with a small collar, which was invented to distribute the load on all the implant surface and to provide for greater stability.
- Premium implant (Sweden Martina)—Implant 2: Internal hexagon connection without a collar.
- Premium implant (Sweden Martina)—Implant 3: Internal connection without hexagon.
- Premium implant (Sweden Martina)—Implant 4: External hexagon connection.

All models consisted of a titanium implant, an abutment, a screw, and a superstructure (Fig. 1). All implants were 13 mm in length and 3.8 mm in diameter corresponding to the dimensions of implants available on the market. To simulate a fixed prosthesis, a simplified superstructure modeled as columns was overlapped over the abutment in all models.

Finite Element Method Analysis

The analysis was performed using 3-dimensional finite elements with tetrahedral solid elements. All materials were taken to be homogeneous and isotropic. Moreover, the interface between the superstructure and the abutment was considered continuous. All models assumed that the implant was embedded in the lower left molar region. The *x* axis was set as the mesiodistal direction, the *y* axis as the tooth direction, and the *z* axis as the buccolingual direction. In this study, complete osseointegration between the implant and the surrounding bone was

Table 1. Maximum Resistance for Each Type of Connection

	Resistance[N]			
	Connection 1	**Connection 2**	**Connection 3**	**Connection 4**
Fixture	414	393	430	365
Abutment	346	316	318	428
Screw	270	215	244	144
FEM				

simulated, and the model was constrained in the *x*, *y*, and *z* directions on the implant surface. In addition, the contact element was used for contacting surfaces between the abutment, abutment screw, and implant, based on a nonlinear analysis of the contact. Furthermore, the coefficient of friction was set to 0.5 between all components such as gold alloy, titanium alloy, and pure titanium. To tighten the abutment screws, all models were set with a preload of 300 N.

A nonlinear dynamic analysis by FEM was used to calculate the transient response of the dental implant systems. Therefore 5 impulsive loads of L1, L2, L3, L4, and L5 were applied at the occlusal surface of the dental implants. In one cyclic loading, an impulsive load of 100 N was applied to the occlusal surface of the dental implant for 0.2 seconds and was stopped for 0.6 seconds.

Fatigue Test

Three implants with a type 1 connection with differing diameters but similar lengths were investigated using a static overload test set-up, according to the standard for fatigue testing of implants and abutments (ISO14801).[20] Each implant was centrally embedded in a polyurethane (PUR; alphadie Top; Schutz Dental, Rosbach, Germany) cylinder, which was framed by a metal sleeve (A2 tool steel) with an inner diameter of 12 mm and a height of 15 mm. The implant platform was placed 3 mm above the PUR to simulate the bone loss. All abutments were placed on the corresponding implants and the screws were tightened according to the manufacturer's recommendation. The specimens were then placed in a stainless steel jig with a 30-degree angle between the implant axis and the direction of loading. The load test was performed using an universal testing machine (Type 20K; UTS testsysteme, Ulm-Einsingen, Germany). A 5-N preload was applied before load until failure to ensure that the test specimens were correctly seated in the jig. A maximum load of 450 N was applied to the samples. Failure was considered to occur when a 100-N load drop was recorded. After testing, each specimen was embedded in clear methylmethacrylate and mid-sectioned along the longitudinal axis by means of a diamond saw. The internal configuration was visually inspected.

Table 2. Results of Fatigue Test

Implant	Fatigue Test (N)
Premium ø3.30, h 13 mm	437.76
Premium ø3.80, h 13 mm	630.43
Premium ø4.25, h 13 mm	576.77
Premium ø5.00, h 13 mm	—

Note: Referring to the aforementioned considerations, we report the Maximum Loads Applicable to Premium/Kohno implants (Sweden & Martina, Italy).

RESULTS

The results of the FEM analysis were divided into the following components: fixture, abutment, and screw. Table 1 sets out the maximum load that each implant component could tolerate. The load-bearing capacity results are lower for the screw of the external hexagon in comparison with other implant configurations. The implant 1 configuration was more reliable in terms of load when compared with the others.

Table 2 shows the total load-bearing capacity of implant connection 1 in implants with different diameters. As is evident from the Table 2, implants with diameters of 380 and 425 mm seem to be more resistant than smaller implants.

Discussion

The effect of connector design on the mechanical resistance of a dental implant's screw joint is still fraught with uncertainties. As a consequence, a large number of configurations have so far been put on the market. Among the different implant connections, there are external hexagon, internal hexagon, and tapered joints. It has been shown that an external hex interface has some advantages, including suitability for the 2-stage method, provision of an antirotation mechanism, retrievability, and compatibility among different implant systems.[21] Moreover, this connection is more versatile for the laboratory technician in solving problems related to the emergence profile and aesthetics. In this connection, the technician may bring the porcelain of a porcelain-fused-to-metal crown much closer to the implant interface.[21] The disadvantages, however, are increased screw loosening, component fractures, and difficulty in seating abutments in deep subgingival tissues. However, internal hexagon systems have some advantages, including easy abutment connection, higher stability, suitability for single tooth restoration, and higher resistance to lateral loads caused by the lower center of rotation and better force distribution.[21] Consequently, some manufacturers have considered modifying this type of connection to improve its stability.

In the present research, 4 different types of connections were evaluated: a modified internal hex connection with a collar (to increase stability), an internal hex connection, a standard connection without hex, and an external connection. These data demonstrated that the internal hex connection with the modification of the manufacturer is much more resistant than the traditional hex. The FEM analysis indicates that most of the force is absorbed by the interaction between hexacon and implant neck in the implant 1 (Fig. 1), whereas the comparison between implant 1 and implant 3 shows a greater stress in the screw and abutment areas. Finally, if we compared implant 1 with implant 4, it is observed that the stress area in this situation is much more diffused on the screw. In terms of load resistance, it is evident that the capacity to support the stress is double in implant 1 compared with implant 4. Furthermore, these data are in agreement with the literature.[22] In fact, Khraisat[22] compared the effect of joint design on the fatigue strength of a Brånemark implant system, which is an external hex and ITI implant, with an internal connection. Their results underlined that internal connections were indeed superior.[22] Other studies highlighted the same conclusions. Moreover, Möllersten et al[23] reported that an external abutment connection was less resistant to bending movements.

In addition, this research confirms the idea that the prosthetic screw, which connects the fixed dental prosthesis to the abutment, is the weak link. A study has already indicated this.[24] It is evident that in the case of overloading, the screw is first to break and thus protects the implant and the bone from damage due to excessive stresses. Sutter et al[25] showed that in a 2-stage implant system, the abutment screw can frequently fracture. The author emphasized that in all 2-stage implant systems, the interface between implant and abutment is the most stressed area of implant prosthesis system because it is located near to the alveolar crest, where the applied force is greatest.

So, to reduce this stress, some manufacturers have devised new forms of connections. In this article, we examined the addition of a collar along the circumference of the connection. This study supports the idea that such a collar around the implant connection can be favorable in the dispersion and reduction of stress. In fact, the presence of this collar with the traditional internal hex connection provided an increase of 20% in resistance to loosening and/or distortion.

For a complete evaluation of this type of connection, we measured the maximum load that this implant can support in relation to different diameters. The results set out in Table 2 indicate that greater diameters can support greater loads compared with small diameters. Although the literature provides an abundance of studies that analyzed the fatigue resistance of dental implants and prosthetic protocols, a standardized protocol of the applied forces is still lacking. In fact, there was no standardization of the applied forces, angle of application, or loading frequencies in the various scientific works. Therefore, a comparison with other types of implants and different connections seem only to have a speculative meaning.

It should be stressed that this research has several points in its favor, including the use of implants of the same manufacturer, with identical diameter and length, and the fact that each experiment was carried out in triplicate to confirm the results. However, limits include the absence of samples of conometrical connections and the small number of implants included.

Conclusion

This research confirms that an internal hex connection may be much more reliable than external ones. In addition, it is evident—as supported by the literature—that the screw between the implant and abutment carries the weak link. As a consequence, several systems, such as the presence of an additional collar, can be useful in protecting the screw and reducing the possibility of its fracture.

Disclosure

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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