

The Effect of Different Implant-Abutment Connections on Screw Joint Stability

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Dental implants with an internal connection have been designed to establish a better stress distribution when lateral external forces act on the prosthesis and minimize the forces transmitted to the fastening screw. In the present study, 10 externally and 10 internally hexed implants were tested with a compressive force applied with an Instron Universal machine. Four cycles of loading-unloading were applied to each specimen to achieve displacements of 0.5, 1, 2, and 2.5 mm. The mean loads for the first cycle were 256.70 N for the external connection and 256 N for the internal connection implants. The independent *t* test did not reveal any significant differences among the 2 tested groups ($P = .780$). For the second cycle, the mean loads needed for a displacement of 1 mm were 818.19 N and 780.20 N for the external connection and the internal connection implants, respectively. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$). In the third cycle, the mean load values for a 2-mm displacement were 1394.10 N and 1225.00 N. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$). The mean loads for the fourth cycle were 1488.00 N for the external connection and 1029.00 N for the internal connection implants. These loads were required for a displacement of 2.5 mm. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$). The results of this in vitro study suggest that the internal connection design of the examined implant system could not prevent screw loosening during overloading. No implant or prosthesis failure was noticed in either group.

Key Words: *implantology, external-internal connection, compressive force*

INTRODUCTION

Dental implants are successfully used for the prosthetic rehabilitation of both partial and complete edentulism. Their use constitutes a viable treatment modality.^{1,2} Originally, dental implants featured an external hex at the prospective connection with the abutment, which

supports the prosthesis. The height of the walls of the hexagon is usually less than 1 mm. It has been claimed that because the short height, the walls of the hexagon cannot provide proper resistance for lateral forces acting on the prosthesis.^{3,4} Therefore, it has been assumed that the bending moments are transmitted to the fastening screw, which connects the prosthetic abutment with the implant. This hypothesis seems to be in accordance with data from prospective and retrospective clinical studies, which suggest that one of the most common complications found in implant-supported prostheses is screw loosening and/or fracture.⁵⁻⁷

Dental implants with an internal connection have been designed and manufactured to establish a better stress distribution when lateral external

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force components act on the prosthetic abutment.^{8,9} It has been postulated that this configuration is probably mechanically superior to that of the external hexagon, since lateral forces are better distributed to the internal conical interface. As a result, the fastening screw does not take a substantial part of the stress of the system.^{10,11} Two multicenter retrospective studies have reported that with the internal connection, the screw-loosening rate is between 3.6% and 5.3%, which is far less than the numbers reported for the external hexagon system.^{12,13}

It should be mentioned, however, that most of the clinical studies for the external hexagon system were performed in the late 1980s to mid 1990s, when torque controllers were not used for the tightening of the fastening screws.^{14–17} In addition, the *in vitro* research on the biomechanical failure of the prosthetic-implant interface is not extended. Furthermore, in most of the tests conducted, a bending force—until failure—has been exerted.^{18,19} Nevertheless, the clinical reality lies far from this simplistic model. It is understood that there is a lack of published research on different modes of failure (fracture) of the restoration, fastening screw, or implant when these 2 differently designed implants (externally and internally hexed) are loaded.

The purpose of this *in vitro* study was to examine the mechanical strength of the implant-prosthesis interface in 2 different implant designs, 1 with an external and 1 with an internal connection.

MATERIALS AND METHODS

Two different companies producing externally and internally hexed implants were randomly chosen from a pool of 15 brands widely used today.²⁰ The selection was performed by a personal computer to eliminate any bias. Ten externally hexed (3i, Palm Beach Gardens, Fla) and 10 internally hexed (MIS Implant Technologies Ltd, Shlomi, Israel) Ti-6Al-4V dental implants were placed in blocks of autopolymerizing polymethyl-methacrylate acrylic resin (Vertex Dental, Zeist, the Netherlands) by means of a surgical handpiece mounted on a milling machine (Bredent BF1, Senden, Germany). Each block accommodated 1 implant, which was fully embedded into the resin. The dimensions of the resin blocks were 45 × 25 × 10 mm. Implants were placed into acrylic resin because its moduli of elasticity ($3.4 \times$

10^5 lb/in^2)^{21,22} is quite close to that of cancellous bone ($3.6 \times 10^5 \text{ lb/in}^2$).²³ The length of each implant was 13 mm, while its diameter was 3.75 mm. The long axes of the implants formed a 130° angle with the loading (vertical) axis. Thus, a simulation of the way in which anterior teeth contact with their antagonists in a Class I Angle occlusion could be achieved.²⁴ Ten plastic UCLA-type abutments were obtained for each implant system. A full contour wax pattern for all specimens was obtained. Each pattern was sprued and sprayed with wax pattern cleaner/debubbler (Jelenco Dental Health Products, Armonk, NY). The wax patterns were then invested with phosphate-bonded investment (Fujivest II; GC America, Allsip, Ill), which was vacuum mixed. The investment was allowed to bench set for 1 hour. The patterns were cast with a Ni-Cr-Mo-Al-Be base metal alloy (Rexillum III, Jeneric/Pentron, Wallingford, Conn). The castings were divested, placed in an ultrasonic cleaner, and inspected under $\times 10$ magnification (Olympus BH2; Olympus Corp, Tokyo, Japan) for surface irregularities. Positive internal irregularities were removed with a round bur (H1 ½ round bur; Brasseler USA, Savannah, Ga). The crowns had a triangular shape to resemble a maxillary central incisor. The length of the crowns was 10 mm, while their width at the incisal edge was 8 mm. The width (mesio-distal dimension) and the thickness (labio-palatal dimension) of the crowns at the abutment/implant interface were the same as the implant platform. All standard laboratory procedures were performed by the same technician. The crowns were connected to the implants using the corresponding titanium fastening screws provided by the manufacturers. A 20-Ncm torque was applied for the final tightening of the screws of the externally hexed implants, while a 30-Ncm torque was applied for the tightening of the fastening screws of the internally hexed implants. These torque values were suggested by the manufacturers. Exact torque values were applied by means of a torque controller (Torq Control, Anthogyr, Sallanches, France).

The crowns were subjected to a compressive force by an Instron Universal test machine 5800 R/5500 R (Instron Corp, Canton, Mass). The applied force was continually monitored by a computer with Bluehill 2.0 (Instron Corp) software, which recorded all data, and a force vs displacement curve for each unit was produced. The diameter of the

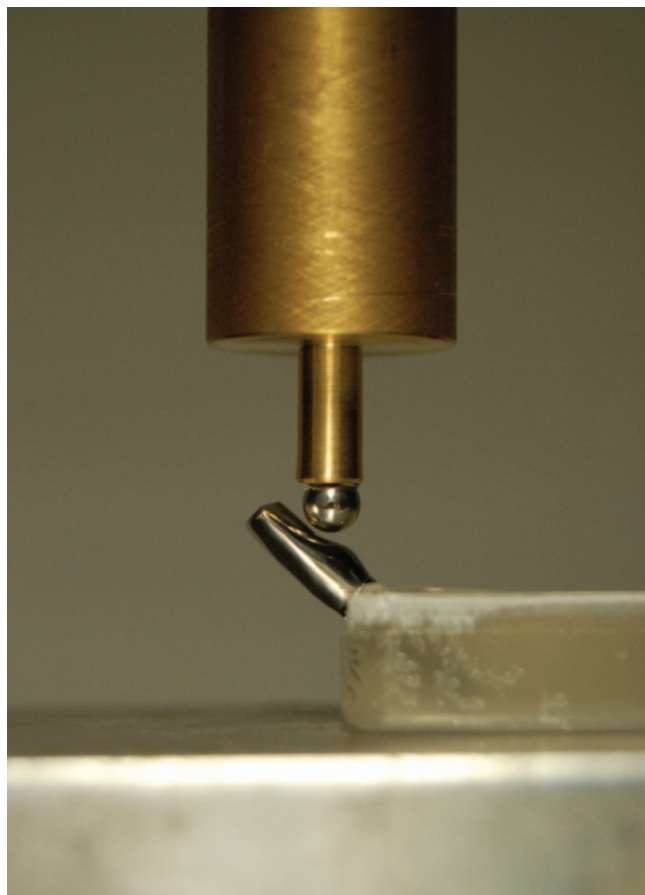


FIGURE 1. The testing apparatus.

ball bearing was 4.75 mm. The effective cross-head speed was 30 mm/min. The force was exerted on the cingulum of the crown, which was 5 mm above the abutment-implant interface.

The force was exerted at a 130° angle to the long axis of the implant/crown assembly (Figure 1).

Four cycles of loading-unloading were applied. The following protocol was followed^{25–27}:

- Cycle 1 0-mm displacement – 0.5-mm displacement in 1 second.
 - 2 sec hold
 - 0.5-mm displacement – 0-mm displacement in 1 second.
- Cycle 2 0-mm displacement – 1-mm displacement in 2 seconds.
 - 2 second hold.
 - 1-mm displacement – 0-mm displacement in 2 seconds.
- Cycle 3 0-mm displacement – 2-mm displacement in 4 seconds.
 - 2 second hold.

- 2-mm displacement – 0-mm displacement in 4 seconds.
- Cycle 4 0-mm displacement – 2.5-mm displacement in 5 seconds.
 - 2 second hold.
 - 2.5-mm displacement – 0-mm displacement in 5 seconds.

The ball bearing was in contact with the specimen without exerting any force before test initiation. Displacement values (0.5, 1, 2, and 2.5 mm) were predetermined and represented the straight distance the load bearing traveled after initiation of the test, followed by a hold at load for 2 seconds before returning to the pretesting condition (Figures 2a and b).

Descriptive statistics and the independent *t* test ($\alpha = .05$) were used to determine the effect of loads causing the above -mentioned displacements among the 2 tested groups.²⁸

RESULTS

The compressive force exerted on the crowns and the displacement that this force caused were recorded with appropriate software (Bluehill 2.0, Instron Corp). Thus, an analysis was possible. An examination of the force-displacement graphs revealed that the external hex implant was able to sustain larger forces. The forces for the external hex implant ranged from 0 to 1506 N, whereas for the internal hex implant, the forces ranged from 0 to 1233 N. The greatest displacement was in the range of 2.56 mm for both implants (Table 1). Moreover, the internal hex implant-abutment connection failed after the fourth cycle. The failure occurred at the fastening screw, which bent.

The means, standard deviations, and minimum and maximum loads for every cycle are listed in Table 2. The mean loads for the first cycle were 256.70 N for the external connection and 256 N for the internal connection implants. The independent *t* test did not reveal any significant differences among the 2 tested groups ($P = .780$). For the second cycle, the mean loads needed for a displacement of 1 mm were 818.19 N and 780.20 N for the external connection and the internal connection implants, respectively. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$). In the third cycle, the mean load values for a 2-mm displacement were

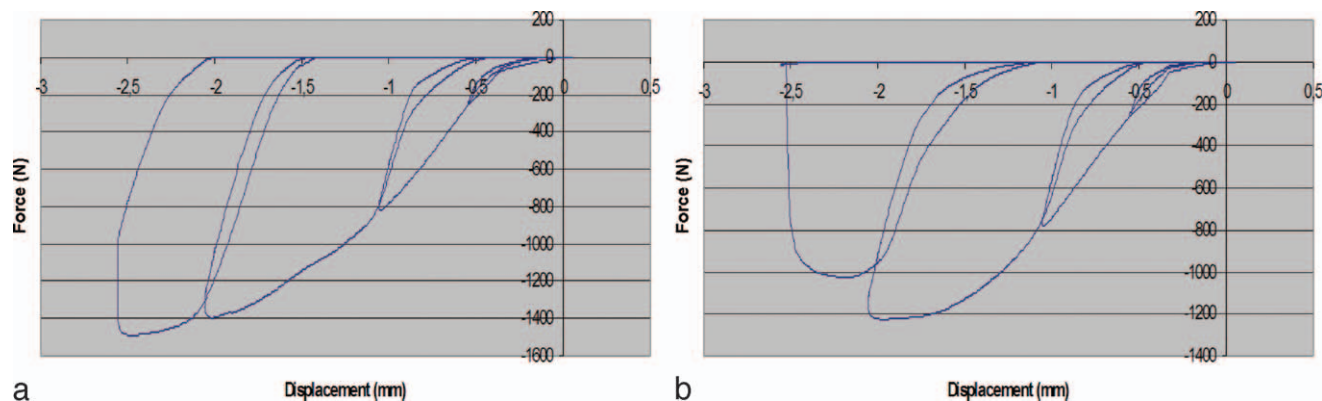


FIGURE 2. Typical load displacement (F-d) curves obtained during experiments for (a) external and (b) internal hex systems.

1394.10 N and 1225.00 N. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$). The mean loads for the fourth cycle were 1488.00 N for the external connection and 1029.00 N for the internal connection implants. These loads were required for a displacement of 2.5 mm. The independent *t* test revealed significant differences among the 2 tested groups ($P < .001$).

It should also be mentioned that all crowns secured on the internally hexed implants were disengaged from their corresponding implants in the fourth cycle. In addition, all fastening screws of these implants were bent.

DISCUSSION

In the present study, a protocol with repeated cycles of preselected, gradually increased displacements was applied onto the “resin block-implant-screw-restoration complex. These displacements have been managed with gradually increased forces and actually included various effects, such as (1) compression of the hex, (2) bending of the abutment (including the crown), (3) bending of the fastening screw, (4) deformation of the resin (in

which the implant is embedded), and (5) deformation of the implant.

The whole concept of the dental implant mechanics has been designed in such a way as to have a weak link that will be the first component that will fail in case the system is overloaded. The screw used to fasten the abutment to the implant usually represents this weak link. Loosening and/or fracture are potential problems for implant abutments and their fastening screws. The results of the present study verified this complication as the abutment screws of the internal hex implants loosened and bent after the application of a mean load of 1225 N. Internal hex implants have been manufactured to decrease this incidence by offering with their internal walls adequate mechanical characteristics to sustain most of the functional occlusal loads without overloading the abutment screws.⁸ However, the results of this in vitro study suggest that the internal connection design of the examined implant system could not prevent screw loosening during overloading.

Another difference between the 2 systems was the diameter of the fastening screw. The diameters of the head and the threaded part of the screw of the external hexagon were bigger than those of the

TABLE 1

Mean peak values of force and displacement for 4 cycles of loading-unloading for the external and internal hexed implants (n = 10)*

Cycles	External Hex Implant				Internal Hex Implant			
	1	2	3	4	1	2	3	4
Force, N	256.7	818.2	1394.1	1488	256	780.2	1225	1029
Displacement, mm	0.54	1.06	2.05	2.56	0.55	1.05	2.05	2.56

*The peak displacement values do not necessarily correspond to the peak force values.

TABLE 2
Descriptive statistics (n = 10) of load values exerted for displacements of 0.5, 1, 2, and 2.5 mm

Group	Cycle (Displacement in mm)	Mean, N	SD	Minimum	Maximum
External	1 (0.5)	256.70	5.97	248.90	265.90
Internal	1 (0.5)	256.00	5.04	248.40	262.70
External	2 (1.0)	818.19	4.87	811.70	824.60
Internal	2 (1.0)	780.20	3.67	774.10	787.00
External	3 (2.0)	1394.10	7.96	1380.80	1405.80
Internal	3 (2.0)	1225.00	5.38	1217.60	1233.80
External	4 (2.5)	1488.00	13.24	1472.10	1506.20
Internal	4 (2.5)	1029.00	3.76	1019.90	1032.70

internal hexagon system. Both screws were made of a titanium alloy. The diameter of the screws is important for the stability of the implant system. When a screw is tightened, a compressive force is generated, maintaining a compressive load between the bearing surfaces of the implant and the abutment.²⁹⁻³³ The preload is concentrated in the stem of the screw and acts from the screw's head to the threads. This preload should ideally be 75% of the ultimate torque to failure to maximize the contact force between the abutment and the implant.^{34,35} It should be mentioned, however, that the manufacturer's instructions should be followed strictly to avoid any damage to the screw. The fastening screw of the external hex implant was tightened to 20 Ncm, while that of the internal hex implant was tightened to 30 Ncm. As mentioned earlier in the discussion, the fastening screw of the internal hex implant system loosened and bent after 4 cycles. It has been described in the literature that screw joints fail in 2 stages.³⁶ In the first stage, an external functional or parafunctional load gradually and effectively erodes the preload torque by causing thread slippage. Then, the critical load exceeds the preload of the screw joint, and it becomes unstable. In the second stage, the external load rapidly erodes the remaining preload, resulting in vibration and micro-movements that eventually lead to screw failure.

The 2 implant systems differed only in the abutment connection (external vs internal hexagon), in the hexagon surface area, and in the diameter and the configuration of the screw. All other parameters were the same. Therefore, any differences in the registered values noticed during this experiment should be attributed to the type of the abutment connection, the hexagon surface area, and/or the diameter of the screw.

Other features of the implant systems, such as the sharpness of the hexagon corners, seem to be important too, since stress concentration may contribute to failure as well.³⁷ In addition, the tolerance of the components is very important for long-term stability.³⁸ In the present study, plastic UCLA-type abutments were used for the fabrication of the implant-supported crowns, since they are widely used due to their lower cost. A disadvantage of the plastic UCLA-type abutments is that their fit is subject to inconsistent water/investment ratios, burn out temperatures, and other variables such as post casting adjustments. As a result, the tolerances of the final product may not be as good as those of UCLA-type abutments with a gold collar, which are machined by the manufacturers. However, a previous in vitro study³⁹ has demonstrated that cast plastic UCLA abutments were significantly more resistive to screw loosening than pre-machined cast UCLA abutments at applied tightening torque of 20 and 30 Ncm.

The observations of this in vitro study indicate that probably the external hexagon implant system examined presents greater structural integrity among the implant, the UCLA-type abutment, and the fastening screw. It should be pointed out, however, that the forces that were applied were much greater than those found during normal function. According to Kiliaridis et al,⁴⁰ the forces in the anterior dentition are usually in the range of 60 to 270 N. Nevertheless, individuals with very high occlusal forces, in the range of 4340 N, have been reported in the dental literature.⁴¹ The forces applied in the present study had values of about 7 to 25 times higher than the forces usually exerted in the anterior region. It should be mentioned, however, that oblique and horizontal forces of great magnitude may be produced during parafunctional

activities. These forces can be as much as six times higher than the functional ones. The combination of high lateral forces and prolonged tooth contact duration may produce a deleterious effect to restorations, which, under normal circumstances, would not fail.⁴²⁻⁴⁴

Testing of the integrity of the abutment-implant connection could possibly be more realistic if a cyclic loading unit within a wet environment was used. However, this approach also presents certain disadvantages since it cannot accurately reproduce mastication, which is a very complex procedure influenced by age, gender, food texture, occlusal scheme, time, and presence of temporomandibular disorders. Cyclic loading can provide only a partial indication as to what may occur during mastication, by causing fatigue to implant components.^{45,46}

It should also be mentioned that more specimens and inclusion of additional implant systems and components are required for definite conclusions to be drawn, which in any case should also be confirmed by randomized control trials.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The external connection implant system required significantly greater loads ($P < .001$) than the internal connection implant system for displacements of 1, 2, and 2.5 mm to be achieved.
2. In all internal connection specimens, the crowns were disengaged from the implants during the fourth cycle, due to fastening screw joint failure.

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