Implant–Abutment Connections

Subjects: General Medical Research

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Definition

Different implant–abutment connections have been developed to reduce mechanical and biological failure. The most frequent complications are loss of preload, screw loosening, abutment or implant fracture, deformations at the different interfaces, and bacterial microleakage. To review the evidence indicating whether the implant–abutment connection type is significant regarding the following issues: (1) maintenance of the preload in static and dynamic in vitro studies; (2) assessment of possible deformations at the implant–abutment interfaces, after repeated application of the tightening torque; (3) evaluation of the sealing capability of different implant connections against microleakage.

1. Introduction

In recent years, geometries of implant connections have been developed with different mechanical, biological, and esthetic characteristics. Two basic geometries are available: internal and external connections. External connections usually have an external hexagon on the implant platform, whereas internal connections can be divided into internal hexagons, internal octagons, and Morse taper connections [1]. The osseointegrated implant and the prosthetic abutment are joined by a screw and have, therefore, been named a screw joint [2].

The external hexagon was the first connection system adopted in modern implantology by Branemark [3], based on the existence of a hexagon (0.7 mm height); however, this connection has been extensively modified in terms of diameter, height, and insertion torque. This kind of connection presents some advantages. First, it is adequate for the two-step surgical procedure preferred by Branemark [3] because it alleviates the second stage and the connection phase with the healing abutment. Second, it simplifies the recording of the external connection in the impression and the prosthetic phase due to its adjustability and compatibility with different prosthetic solutions. However, it also presents a number of disadvantages, such as little contact length between the restoration and the hexagonal part of the implant head, some degree of rotation between the platform and the internal hexagon of the restoration, and high tension created in the screw connection. It has been speculated that under high occlusal loads, the external hexagon might allow for micromovements of the abutment, causing instability of the joint, which may result in abutment screw loosening or even fatigue fractures [4][5][6]. The literature has shown the loosening rate of this type of connection to be between 6% and 48% [7], thus presenting a mechanical difficulty for the maintenance of the preload (torque for the removal of the pillar must be 10% lower than that of installation) [8][9].

Internal connections have been introduced with a Morse cone of different degrees of inclination, depending on the commercial brand [10], to lower or eliminate the mechanical complications of the external connection and to reduce the stress transferred to the crestal bone [11][12][13][14]. In the internal hexagonal system, the hexagon and the screw pass into the implant body so the prosthetic component is more stable. The internal hexagon connection was developed as an evolution of the external hexagon, with the aim of increasing the load absorption under a lateral force. This reduces mechanical and biological complications, such as screw loosening, fracture, and marginal bone loss. The greater depth of the connection in the fixture body allows more homogeneous dissipation of the mechanical stress; the stress is spread on the implant wall and, consequently, to the bone surrounding the entire implant and not only at the crestal level. [15] A conical connection is a particular kind of internal connection in which the abutment is fixed to the implant using the mechanical properties of a machine taper. A male member of a conical shape fits into a female socket, which has a matching taper of equal angle. The connection works by locking the two components by mechanical friction between the wall of the abutment and the implant. Although mechanical friction has been demonstrated to be strong enough, implant companies have also implemented screw retention and antirotational systems. However, to date, no qualitative data exists comparing the mechanical behavior of external and internal connections [7]. The internal connection using a Morse cone creates a more accurate bond between the implant and the abutment, which reduces the movement of the interface and decreases the loosening of the screw (torque for the removal of the abutment must be 17% greater than that of installation) [8][9]. The Morse cone has an internal cone of 8° or 11°, which can protect against screw loosening [9][16].

As described previously, the different implant–abutment connection designs have very different characteristics, which can affect mechanical stability. The failure of an implant is related to two problems: biological and mechanical factors. Biological causes essentially relate to periimplantitis, which affects the soft and hard tissues around the implants, whereas mechanical causes involve prosthetic components, namely, overload of the prothesis–implant–pillar complex, implant fracture, abutment fracture, loosening of the screws, and fracture of the superstructure (metal/ceramic) [17][18].

Abutment screw stability can be affected by preload, the effect of settling, and screw geometry[2][19][20]. Preload is the force that is generated when the screw is tightened using a given torque [2][19][21]. Torque is defined as the movement produced by applying tangential force to the screw and is usually expressed in newton centimeters (Ncm). When applying the preload to a screw, the connected elements are kept in compression, and the screw receives small impacts because most of the load is absorbed by the components of the implant–abutment junction [22]. The initial preload on the screw is usually inserted by applying torque using a torque wrench. One of the major causes of screw loosening is the “loss of preload”. Only 10% of the initial torque is transformed into preload, whereas the remaining 90% is used to overcome the friction between the surface irregularities [2][19][21]. In the tightening of the components of the connection, tension occurs with a consequent compression between the structures of the joint. Screw loosening is one of the most common mechanical complications of implant treatment, with an estimated annual rate of 2.1% [23]. Estimated rates are 10.4% and 20.8% over 5 and 10 years, respectively [24]. From a clinical perspective, the loosening of the screw is greater in external connections than in internal connections, with an incidence of loose screws of 38% in external hexagon systems [25][26]. However, the ratio of torque to preload is not linear and is affected by several factors: coefficient of friction, geometry, and properties of contact surface materials. The first is the most influential and depends on the hardness of the threads, the finish of the surfaces, the lubricant used, and the tightening speed [27]. A preload torque between 10 and 35 Ncm is recommended by different manufacturers, depending on the screw manufacturing material and the morphology of the abutment–implant connection [2].

2. Discussion

2.1. Maintenance of the Preload According to the Type of Connection

(a) Maintenance of preload after single tightening

The results of Jorge et al. and Al-Otaib et al.[28][29] corroborate those of previous studies, which found that all detorque values were lower than the insertion torque in the baseline in the external hexagon connection and Morse taper (Jorge et al.) and the internal connection (Al-Otaibi et al.). The loss of torque loss a few minutes after torque application is expected and can be explained by a phenomenon known as the sedimentation effect or embedment relaxation [25][30]. This phenomenon assumes that all machined surfaces exhibit a certain degree of microroughness, due to which the surfaces are not perfectly plane. Thus, when the screw receives torque for the first time, contact between the threads occurs; after a few seconds or minutes, the surfaces between the components in the contact area deform and flow. This explains why, clinically, it is recommended to retighten the retaining screw 10 min after the initial torque is applied. According to Breeding et al. [30], the deformation and flow of the components can reduce the torque by 2% to 10% in the first moments after tightening.

Investigation of the effect of different maintenance times of torque application and screw loosening was the aim of the study of Al Otaibi et al. [29] in internal hexagon implants. The mean RTVs were lower than the applied torque for all the protocols. The highest mean RTV was found in the immediate protocol. Maintaining the torque for a prolonged time (10 or 30 s) was not significantly associated with higher preload compared to instant torque application. One possible elucidation in this regard could be that when torque is maintained for a certain time (10 or 30 s), a significant portion of the plastic deformation that occurs mainly during the first few seconds is compensated for, avoiding excessive loss of the detorque value compared to the group submitted to an instant application of torque [31].

(b) Maintenance of the preload after multiple tightening

Because the retorque value measured after screw loosening is an indirect measurement of the remaining preload, the aim of these studies was to evaluate the torque maintenance of the retention screws' abutment, in different connections, after repeated tightening/loosening cycles of the screws. The torque loss, after multiple tightening, demonstrates that part of the insertion torque used to generate the preload is lost even when no external force is applied to the system. In general, RTVs were found to be lower than tightening torque values. This reduction can be attributed to the phenomenon of the settling effect [32][33][34]. The settling effect occurs because no surface is completely smooth, which causes the presence of high spots on the internal threads of implants and screw threads. These high spots become flattened because they are the only contacting surfaces upon application of the initial tightening torque. Consequently, the torque required to remove a screw is lower than the torque initially used to place it.

Clinically, the current results indicate that the retention screws should be retightened after 3 min of insertion before masticatory loading occurs. In addition, a careful follow-up of the implant-supported prosthesis should be performed because simulated masticatory loading induces screw loosening [35].

In the study of Al-Otaibi [29], removal torque was found to be 79.8% of the applied torque. The results of this study also showed that the retorqued-once application technique resulted in significantly higher RTVs compared to those of the torqued and retorqued-twice techniques. When torque is applied for the first time, some of the torque is used to flatten surface microroughness on the implant's internal threads and the screw surface. The second application of torque generates the desired preload, and this may explain why the retorqued-once application technique resulted in higher RTVs than the torqued technique [36]. Corroborating these results, the study of Kim et al. (2020) confirmed that it should be taken into consideration that loss of preload due to the settling effect can lead to screw loosening. The mean values of initial removal torque were higher in the internal octagon connection than those of the external connection.

In conflict with these studies, Cashman et al.[37] found no significant difference in RTVs, although the focus of this study was limited to the comparison of internal connection abutments from two manufacturers. The literature reports different preload results because of the use of many different methods for its measurement and evaluation.

The results of Rocha Bernardes et al.[20] did not observe any significant preload change (with titanium screws) after five sequences of tightening/untightening, corroborating the findings of Cashman et al. The samples were used a single time, and no implant was ever reused. This study also found that external hexagon implants showed the lowest preload values generated in the cervical third of the implant, whereas the internal hexagon implants displayed the highest values for preload. Conical implant connections demonstrated stronger structural reinforcement within the internal connections, regardless of whether a torque of 20 or 30 Ncm was applied; however, the latter torque is more appropriate for this implant design. According to this study, a torque of 32 Ncm was mechanically better for Morse taper implants because it did not apparently deform the implant walls more than the deformation caused by a torque of 20 Ncm, whereas it also increased the resistance of the screwed joint to external loads. Screw torque values are also important variables in the retention system of an implant, the stability of which is not determined solely by the interface design or the screw type. Ideal torque amounts for each type of connection should be evaluated. Screw tightening should result in the optimal preload that minimizes screw loosening and fracture [20].

(c) Maintenance of the preload after tightening and the application of cyclical load

Cyclic loading forces during physiological function that do not exceed the maximum strength of an implant–abutment connection may loosen the implant–abutment connection gradually or make it fail due to fatigue. The reason for fatigue failure is either a lack of force-fitting or form-closure of the connection design. The critical reason for the loosening of the implant–abutment connection is the loss of preload at the abutment screw and the resulting unscrewing or fatigue failure of the screw material. RTV has been used as a measurement of preload in numerous studies to evaluate interface stability following fatigue tests [14]. The torque loss may be explained by the fact that the screws are subjected to a mechanical effect known as embedment relaxation, described previously. Because the contacting surface between the screw and the implant cannot be machined to be perfectly smooth, high spots will be the only contacting surfaces when the initial tightening torque is applied. The contacting surface will adapt to smooth the surface, thus leading to preload loss [38].

Study results relating to the maintenance of preload after multiple tightening and application of cyclical load have presented diversity that may be explained by the range of the applied load (from 10 to 1450 N), number of loading cycles (from 2000 to 5 × 10^6), different fatigue machines, and the number of samples evaluated (from 30 to 120). Some studies compared the different implant designs available, and others included only one kind of connection system.

Many authors indicate that external connection systems present better fatigue behavior due to the differences in force-fit in the connection design [39][40]. In agreement with these findings, we identified the studies of Shin et al. and Gil et al. [41][42]. Regarding fatigue results, Shin et al. showed that the external butt joint was more advantageous than the internal cone in terms of postload removal torque loss. In the study of Gil et al., the external hexagon interface showed superior results compared to the internal hexagon interface. In the study of Jorge et al., after mechanical cycling, a statistically and significantly lower loss of detorque was verified in the Morse taper group compared to the external hexagon group.

Regarding implant design, there was no difference found between the behavior of internal connection and external hexagonal implant systems in the studies of Piermatti et al., Tsuruta et al., and Tsuge et al. [21][43][44]. The results of Piermatti et al. suggest the importance of screw design on the stability of the screw and maintenance of preload. In the study of Tsuruta et al., after 2000 cycles of compressive tensile loadings, RTVs of the abutment screw presented no statistical differences among the three groups (internal, external, and conical connection); however, this study used the fewest loading cycles. Finally, Tsuge et al., revealed that the postloading preload was significantly higher than initial preload in both internal and external connections and indicated that the implant–abutment connection did not have an effect, but the abutment screw material did. Titanium alloy abutment screws were less likely to come loose.

The load application reduced the mean values of the preload significantly in external hexagon connection implants in the studies of Butignon et al. and Khraisat et al. [45][46]. Although there was a significant decrease in the postload reverse torque values in the study of Khraisat et al., screw loosening could not be detected statistically. This may indicate that the remaining tightening torque would serve clinically for a longer period. Similarly, but in the case of an internal connection, the study of Xia et al. [47] revealed that in comparison with the unloaded specimens, the specimens that experienced fatigue loading had decreased RTVs. It was also concluded that fatigue loading would lead to preload loss.

(d) Maintenance of the preload after multiple tightening and the application of cyclical load

In the studies of Cashman et al. and Arshad et al.[37][48], the aim was to investigate if repeated screw joint closing and opening cycles would affect the abutment screw removal torque.

The results of the study of Arshad et al. indicate that the RTV was considerably lower than the insertion torque in the conical hexagon connection. These results corroborate previous studies, which reported that all screw types display some decay in preload with repeated tightening. The result depends on screw material, intrinsic metallurgic properties of the raw material, and the manufacturing process. These factors could explain the variations observed by Arshad et al. in the torque values between samples of the same group. Previous studies have shown that not only screws from different manufacturers but also screws from different lots of the same manufacturer could lead to different maximum preload torque before fracture [22][49]. Clinically speaking, increasing the number of times an abutment screw is closed and opened will eventually result in the reduction of removal torque and an increased risk of screw loosening. Arshad et al. also observed, in conical hexagon internal connections, that using a new screw could not significantly increase the value of removal torque and that restricting the amount of screw tightening was more important than replacing the screw.

Cashman et al., did not determine a significant loss of RTV postfatigue loading despite similar test parameters. The purpose of the study of Cashman et al. was to compare the abutment fatigue resistance to a simulated function in a specific brand control abutment relative to a third-party-compatible abutment. The differences in chemical composition, manufacturing, and surface treatment indicate a need for independent verification of functional compatibility. Different abutment manufacturers result in a difference in RTV postfatigue loading. The control abutment demonstrated a greater RTV than the third-party-manufactured component.

2.2. Assessment of Possible Deformations at the Different Interfaces after Repeated Application of the Tightening Torque

Scanning electron microscopy (SEM) was carried out to determine the characteristics of the interface microgap, compare thread geometry, and evaluate surface characteristics between systems.

SEM examination was conducted by Khraisat et al. (external hex implants) and Tsuge et al. (internal and external implants) [45][37]. These studies evaluated the surface changes of the abutment screw thread and the implant hexagon corner, before and after loading, with 1 × 10^6 cycles (Khraisat et al.) and 2000 cycles (Tsuge et al.). In the study of Khraisat et al., mild burnishing and scuffing of the abutment screw thread surfaces were observed, after tightening, in control specimens that were not loaded. Marked burnishing was observed at the hexagon corners on the compression sides.

In the study of Tsuge et al., damage was observed on the threads of the abutment screws and the screw surfaces (roughening, stemming) on the upper and lower flanks, which was probably due to screw tightening. However, no abnormal wear or damage due to micromovement or bending caused by cyclic loading was observed on the abutment screws in any of the samples.

SEM was also carried out in the study of Cashman et al.[37] after 5 × 10^6 cycles of loading to compare thread geometry and evaluate surface characteristics in internal connections. Differences in surface finish were visualized in postfatigue cycling, such as ductile delamination and rough surfaces in the profiles of the threads. Visual differences at the macro/microscopic level were also apparent in the thread geometry, with third-party abutments demonstrating considerably greater variation in geometrical architecture than control specimens.

2.3. Evaluate the Sealing Capability of Different Implant Connections against Microleakage

In the systematic review of Mishra et al. (2017)[50], a maximum study showed that there was some amount of microleakage at the abutment implant interface. External hexagon implants failed to completely prevent microleakage in both static and dynamic loading conditions of implants. Internal hexagon implants, particularly internal conical (Morse taper) implants, are highly promising in the case of static loading and showed less microleakage in dynamic loading conditions. Torque values recommended by the manufacturer should be strictly followed to achieve a better seal at the abutment–implant interface. Zirconia abutments are more prone to microleakage than titanium abutments, and their use should be discouraged. Zirconia abutments should only be restricted to cases where there is a high demand for aesthetics. These results corroborate the study of He et al. [51] (2019) in which the conical connection showed more resistance against the formation of microgaps at the implant–abutment interface than the external hexagonal connection. Additionally, Gil et al. [52] concluded that internal connections had a smaller microgap than external connections, with significant statistical differences. Very good adaptation between the implant and the screw-retained abutment was observed; in many cases, the distances were smaller than the bacteria diameter, thus preventing infiltration of microorganisms. In contrast, Ricomini Filho et al. [53] observed a better bacterial seal in the group with an external hexagon with a universal post than in groups with conical connections. These authors found that the external hexagon connection could have acted as a physical barrier, blocking bacterial penetration toward the inner part of the implant. SEM micrographs show no bacterial cells on the surface of the external hexagon abutment screw, thus confirming the microbiological assay. The methodology of rubbing a paper point on the inner part of the implant was probably unable to assess the microbial colonization on the implant platform, justifying the need for future studies to confirm these findings.

In vitro investigations showed that a major portion of conical connection systems presents a microgap under static forces smaller than 10 µm [54], demonstrating a better fit of the abutment into the fixture but not eliminating it completely. Other authors have shown minimal abutment movement and microgap formation under axial and oblique forces but good resistance to torque loss and screw loosening [55]. Internal cone implants have interface force transfer characteristics similar to those of a one-piece implant, but an absolute bacterial seal cannot be achieved in a two-piece implant system. For these reasons, conical abutment should be preferred to other connection systems to minimize bacterial microleakage [56]. Corroborating these findings, Gherlone et al.[57] tested, in an in-vitro study, a new internal conical connection design characterized by a double-taper principle. The authors evaluated and compared a new connection design, named double-action tight (DAT), with other internal connections. To investigate bacterial microleakage, the inner part of each system was inoculated with an Escherichia coli suspension. They found that in the

DAT connection group, 7 of 10 total implants showed no bacterial infiltration at 96 h. This new internal conical design should reduce bacterial infiltration by constructing a physically tight connection with a high level of precision in the submicrometer range. Additional studies are necessary to better understand the stability of this new type of internal connection over a longer period, with different bacteria and subject to the mastication function.

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Keywords

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