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**Mechanical stability of Morse taper implant – abutment
connection ; A focused review**

Universidade Fernando Pessoa
Faculdade de Ciências da Saúde

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Work presented to the University Fernando
Pessoa as part of the requirements to obtain
Master's degree. In .Dentistry.

Resumo:

O objetivo principal deste estudo foi realizar uma revisão sistemática sobre a integridade mecânica das conexões cone Morse de implante em relação à presença de microgap e manutenção do torque.

Uma ampla pesquisa eletrônica foi realizada nos bancos de dados PubMed, Embase e Medline com as palavras chaves: dental implant” e “dental abutment” e (“conical” ou “taper” ou “cone”). “removal torque” e “Morse Taper”, “torque loss” e “micro gap size”

Estudos in vitro demonstraram que os pilares cônicos têm melhor desempenho, no que diz respeito ao selamento bacteriano e a manutenção do torque e estabilidade do pilar, do que os pilares não cônicos.

Estudos in vivo mostraram que as taxas de sucesso e sobrevivência dos sistemas de implantes cone Morse comparadas aos outras, são quase comparáveis; porém os implantes com conexão cone Morse mostraram menor perda ossea marginal.

Conclui-se , com esta revisão sistemática, que o uso de implantes com conexões cone Morse parece ser mais vantajoso, pois de mostraram ter melhor desempenho em termos de estabilidade mecânica e selamento bacteriano.

Palavras-chave: systematic review, dental implant, dental abutment, Morse Taper, implant–abutment connection, microgap and seal performance, torque maintenance, fatigue resistance.

Abstract:

The main aim of this study was to carry out a systematic review on the mechanical integrity of Morse taper implant-abutment connections in relation to the presence of micro gap and torque maintenance.

A broad electronic search was conducted using PubMed, Embase, and Medline databases with the logical operators: “dental implant” AND “dental abutment” AND (“conical” OR “taper” OR “cone”). “Removal torque” and “Morse Taper”, “Torque” and “micro gap size”

In vitro studies demonstrated that conical abutments are more advantageous than non-conical abutments, and appeared to be superior in terms of bacterial seal performance, torque maintenance, and abutment stability.

In vivo studies showed that the success and survival rates for conical and non-conical implant-abutment systems are almost comparable; however, the results indicated that, conical connection implants are more favourable as the majority of cases showed less marginal bone loss around.

This systematic review points out that the use of conical implant–abutment connections seem to be more advantageous as they clearly showed better performance in terms of mechanical stability and bacterial seal.

Key Words: systematic review, dental implant, dental abutment, Morse Taper, implant–abutment connection, microgap and seal performance, torque maintenance, fatigue resistance

Acknowledgement:

I must express my very profound gratitude to my thesis advisor Professor Jorge Pereira for the continuous encouragement and support throughout the process of researching and writing this thesis.

I would also like to specially thank my parents for providing me with unfailing support; this accomplishment would not have been possible without them. Thank you.

Samantha Al-Dujayli

Porto, 2017

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Introduction:

Dental implants have achieved long-term success due to the osseointegration of the highly biocompatible titanium integrating to the surrounding bone, (Branemark PI et al. 1977; Albrektsson et al. 2012).

Following the establishment of osseointegration, the success of implant system depends on the mechanical and biological stability of the contacting metal components (Implant abutment interface) (Branemark PI et al. 1977; Albrektsson et al. 2012; Zarb GA, Schmitt A2010).

The implant-abutment interface has been reported to be a significant factor in terms of load transfer, adverse biological responses, and technical complications.

In every implant system, the efficiency of the implant-abutment connection (interface) system depends on several factors, such as component design, connection geometry between implant and abutment, mechanical fit or contact between the implant and its set inner surface on the abutment, component mechanical and physical properties, and torque application (Carotenuto G, Palumbo et al. (1999).

Implant systems differ in terms of the design of the implant-abutment interface with particular differences between both conical and non-conical connection systems (indexed external or internal connections). The implant- abutment connection represents the weakest point of dental endosseous implant fixtures, as it must be strong enough in order to withstand maximal and permanent masticatory forces as well as penetration by bacteria.(Schmitt CM1, et al. 2013) .

There are approximately 20 different implant/abutment interface geometric variations available. The geometry is important because it is one of the primary determinants of joint strength, joint stability, and locational and rotational stability; it is critical to and synonymous with prosthetic stability (Binon PP Implants and components 2000).

The Implant–abutment connections have been broadly classified as External and Internal connections. The external Hexagon Implant abutments have been widely used, but despite their widespread use, failure rates ranging from 6% to 48% after 5 to 10 years of clinical

service (have been reported in the literature) (Binon PP Implants and components 2000; Maeda y et al. 2006; Tabata LF et al. 2011), The failure was mainly due to loose abutments, inadequate microbial seal and screw fracture.

A 22-month follow-up on external hex implant prostheses in a private prosthodontic practice reported the incidence of loose screws in fixed and removable prostheses at 27% and 32%, respectively (Walton JN, et al.1997).

To overcome some of the inherent design limitations of the external hexagonal connection, a variety of alternative connections have been developed. The most notable are the cone screw, the cone hex, the internal octagonal, the internal hexagonal, the cylinder hex, the Morse taper (Binon PP Implants and components 2000).

Considering the novelty in technology on dental implant joints, Jokstad et al. noted that, the development of internal connections showed improved results regarding aesthetic outcomes and mechanical stability.(Jokstad A, et al .2003).

Currently, common examples of internal implant-abutment connection designs are the internal hexagonal and the Morse taper connection. (A unique design feature of the Morse taper implant-abutment connection is an internal joint design between two conical structures. This connection was developed by Stephen A. Morse, in 1864).

The stability of the implant – abutment interface (connection) is an important factor that influences load distribution to the marginal bone. However, adverse biological responses and mechanical complications can occur; the most frequent complications arising from misfits of the implant-abutment interface include a) biological complications that include increased load transfer to the bone, bone loss, and development of microflora in the microgap between implant and abutment (Michalakis KX et al. 2003 ; Jansen VK et al. 1997 ; Quirynen M et al. 2002) , and b) Prosthetic complications that include screw loosening or fracture and implant loss (Burguete RL, *et al.* 1994).

Regarding the mechanical properties of implant connections, it has been assumed that different abutment connections might provide greater resistance to displacement that is caused by excessive occlusal forces.(Kitagawa T, et al. 2005) In this regard it has been speculated that this displacement will increase stress/ strain on the endosseous implant thus promoting the acceleration of marginal bone loss.(Quaresma SE,et al. 2008 ; Lin CL, et al. 2007).

At the present time, it's still not certain and unknown as to whether one connection system currently available might be more beneficial and superior to others in terms of the presence of microgap and seal performance as well as torque maintenance.

In relation to the influence of the presence of a marginal gap between the implant and abutment on the implant system long term prognosis, it was shown that the microgap could lead to an increased loss of marginal bone due to the penetration of bacteria into the implant-abutment interface which could compromise the health of the periimplant tissue and consequently lead to implant failure (compared to an implant without a gap that permits bacterial invasion).(Schmitt CM1, et al. 2013).

However, in case of conical implant-abutment connection systems, It has been claimed that this is not as much of an issue as the microgap is much smaller with less leakage at the implant-abutment interface, therefore, hindering or preventing bacterial colonization and growth. (Tesmer M, et al. 2009);(Merz BR, et al. 2000).

Regarding the torque maintenance and mechanical stability, it has been claimed that, the internal conical implant-abutment connection is considered to be mechanically more stable and tighter than flat-to-flat connections or tube-in-tube connections. (Harder S,et al. 2010 ; Seetoh YL,et al. 2011).

Concerning the reported complications, success and survival rates for conical connections; (Arvidson et al. 1998), reported no screw failures or joint problems over a 3-year period on 310 implants in mandibular prostheses. In a subsequent investigation of 517 implants with a 5-year follow-up, Arvidson et al reported no prosthetic or abutment screw loosening, fracture, or complications).

However, some clinical reports have reported screw loosening. For instance, a multicentre study of 174 implants performed by (Levine RA, et al. 1997) reported that 8.7% of prosthetic screws and 3.7% of cone abutment screws were loose at 6 months.

Given the reported successful follow-up of conical connection implants, this study aimed to assess the mechanical stability and success of Morse taper implant-abutment connections (contact surfaces), in relation to the presence of microgap and bacterial seal performance as well as the maintenance of torque.

I. Methodology:

A broad electronic search was conducted in Medline/PubMed database from 1997 up to 2017. The following search items were explored: “Morse Cone” and “implant-abutment connections”, “removal torque” and “Morse Taper”, “torque” and “micro gap size” “Biofilm” and “removal torque”, “fatigue” and “implant-abutment”, “fracture” and “implant-abutment connections”.

The eligibility inclusion criteria used for this article search were: Meta-analysis; systematic reviews; randomized controlled trials; clinical trials; Pilot studies; comparative studies, prospective cohort studies; as well as articles and reviews written in English, language.

The literature search selection accepted the following tests: in vitro laboratory trials using synchrotron X ray high-resolution radiography (SRX) and scanning electron microscopy (SEM) and X-Ray 3 Dimensional Micro tomography.; In Vivo clinical trials performed in human under Cone Beam Computed Tomography and performed in animal under radiographic evaluation. Biomechanics by finite element analysis (FEA) or photo elastic spirometry.

II. Development / Results:

The characteristics and outcomes for the reviewed in vitro and in vivo studies are summarized in tables I ; II ; III ; IV ; V ; VI / Attachment.

A. In Vitro studies:

1. Microgap size and seal performance: see table I / Attachment

Nine in vitro trials investigated the bacterial leakage of the implant–abutment interface.

The Following bacterial species were used: *Escherichia coli*, *Aggregatibacter actinomycetemcomitans* (Aa), *Porphyromonas gingivalis* (Pg), *Streptococcus sanguinis* (Ss), *Pseudomonas aeruginosa* (Pa), and *Streptococcus aureus* (Sa). Only One study performed by (Harder S, et al 2010), investigated microbacterial endotoxin leakage from the implant–abutment interface using lipopolysaccharides (LPS) from *Salmonella enterica* (Se).

Only two in vitro trials assessed human saliva leakage into the implant–abutment interface, performed by Pereira, J. et al (2016). ; And Nascimento, et al (2012).

The findings of the included studies in this review reported the following:

- There was no 100% seal of the implant–abutment interface to the outside environment regardless of the design of the implant–abutment interface. As it was demonstrated that Even if an abutment was tightened to an implant under completely sterile conditions, bacterial contamination into the interface was still evident in most cases (Table I).
- Only one study showed 100% bacterial seal using the Ankylos implant-abutment system which hindered contamination with Pg (*Porphyromonas Gingivalis*). However, when another organism, Aa, was tested it was demonstrated that this particular bacterial species could still penetrate into the Ankylos implant-abutment interface. Bacterial leakage was also observed in all implant- abutment connection systems under loading (in vitro). On the other hand, Ricomini Filho et al (2010) showed no leakage at all when testing the external hex implant-abutment connection system using Ss. Without loading.

- An in vitro laboratory study conducted by Pereira J. et al in 2016 to assess the biofilm (Saliva) accumulation at Morse taper and external hexagon implant-abutment interfaces after fatigue tests which simulated six months of function, the study. highlighted that biofilm density at Morse taper joints were significantly lower in comparison to those recorded at external hexagon implant-abutment joints after fatigue tests in a simulated oral environment, the results of this study came in agreement with those of Nascimmento et al. (2012) who also reported significantly less human saliva penetration in to the implant–abutment interface in conical connection systems.

Two researchers demonstrated the sealing capability of different implant-abutment connections using dyes (toluidine blue and gentian violet) by measuring particle absorption with spectrophotometric analysis. Coelho et al (2008) and Goss et al (1999). They both documented significantly lower dye leakage with the Morse Taper and internal hexagonal connection in comparison to the tri-lobed internal connection system. Leakage was recorded in all systems and decreased significantly as tightening torque was increased to the values recommended by the manufacturers.

- It was shown that the fit between the implant-abutment connection assemblies is a decisive factor for the presence and the magnitude of the microgap at the implant – abutment interface. Gross et al (1999) for instance, reported that with higher abutment tightening torque values, the microgap size decreased, they concluded that, the decrease was related to the more precise fit between the implant-abutment connection assembly, however too high tightening torque forces could lead to distortion (abrasion) at the implant-abutment interface, resulting in higher microgap size.(Coelho et al (2008) reported),
- Later on in (2015) GEHRKE, Sergio Alexandre et al. reported that the linear area of contact between Morse taper abutment and the implant increased as torque augmented, it was concluded that higher insertion torque values in a conical internal connection increase the fit (contact) of the implant-abutment interface. The results obtained supported the outcomes of the previous similar studies.

- A study conducted by D'Ercole, S. et al in (2014) assessed whether there is a correlation between the value of the tightening torque and the presence of bacterial leakage at Morse cone implant-abutment interface, it was demonstrated that, there is a correlation, as with increased tightening torque values, the bacterial leakage was reduced, the results obtained, supported the data reported in the literature.

However it was shown that the sealing capability was:

- (1) Different with every implant system regardless of the type of connection used, and,
- (2) It was evidenced that when using pure conical implant-abutment connection, the bacterial contamination at the interface seemed to be significantly less as compared to other connection systems.

Although conical implant–abutment connection systems were able to reduce bacterial contamination significantly, they were unable to prevent microbial endotoxin leakage into the interface/ microgap area under loading. (Harder S, et al. 2010).

- (3) Under the scanning electron microscope (SEM) , Microgaps were evident in all systems, but were generally less than 10 μm for all connections tested. (Jansen VK, et al. 1997).

On using Finite Element Analysis (FEM), it was shown that The mean microgap size was significantly larger for flat-to-flat interface systems compared to conical interface systems.

(Merz et al 2010). For instance, reported the presence of a microgap for external hexagonal connection systems on the tension side of the implant under oblique or horizontal loading simulation. (Pessoa et al. 2010) also reported microgap formation on tension sides for internal hexagonal and external hexagonal connection systems. Conical implant-abutment systems did not seem to develop statistically significant microgaps.

Using synchrotron micro-tomography SRX (CT), (Blum, K. et al 2015) compared different Morse taper implant-abutment connection systems in relation to the microgap size after fatigue test, which simulated one year of function, and reported that All implants exhibited a microgap ranging from (0.1–0.14 μm) on the coronal part of the IAC(implant-abutment connection) and 1.2 μm (range 0.12–5.0 μm) in the lower part of the IAC between the implant and abutment prior to loading, The gap size increased with cyclic loading with its changes being significantly higher within the first 200,000 cycles.

2. Loading / fatigue performance and Torque maintenance:

Eleven in vitro trials assessed the changes in preload, mainly the loss or gain of the Implant – abutment removal torque.

The change in torque was evaluated after initial tightening and, by how it was influenced by the following:

- (1) Fatigue loading.
- (2) The presence of biofilm in the Implant-abutment interface.
- (3). Increased/decreased initial tightening torque.
- (4) Repeated tightening and removal cycles.

Two researchers; (Pereira, Jorge. et al. 2016, and Ricomini, Filho. et al. 2010), addressed seal performance in addition to load / fatigue performance, whereas others were mainly focused on stress/load performance, particularly dealing with load fatigue performance of the implant-abutment connection.(Ricomini Filho et al. 2010; Norton MR 1997; Koutouzis T, et al. 2011).

(Pereira Jorge, et al. 2016) conducted an in vitro study to evaluate the influence of fatigue loading on the removal torque values of Morse taper and external hexagon abutments in a simulated oral environment, and concluded that the mean values of torque loss, microgap size, and biofilm density recorded at Morse taper joints were lower in comparison to those recorded at external hexagon implant-abutment joints after fatigue tests which simulated six months of normal chewing function.

(Ricomini, Filho. et al. and, Park et al 2010). Demonstrated torque loss and consequently Preload loss following initial tightening of the abutment to the implant before loading, the External hexagonal connection showed significantly higher preload loss after loading than the two conical connections that were similarly assessed.

(Shin, HM.; et al in 2014) on the other hand compared the removal torque loss between external hexagon and two conical implant abutment systems of different diameters after loading and found out that the reverse torque values for the regular external hexagon is higher than that of the regular diameter Morse taper implant abutment connections after loading, and the percentage of preload loss was higher for Morse taper than external hexagon connections, , the results of this study concluded that the implant-abutment interface design and diameter affect the screw joint stability.(The outcome results of this study were surprisingly contradicting with what was reported in the literature as it showed that the external hexagon is more advantageous than the internal cone in terms of torque maintenance, however the difference was not statistically significant, and it was mainly attributed to the preload loss caused by the abutment sinking phenomenon).

(Feitosa, Pinheiro Paulo Cesar et al. in 2013) for instance carried out an experiment to compare the initial reverse torque (before fatigue test) and final reverse torque (after fatigue test which simulated one year of chewing function) of three different implant-abutment connection systems (External, Internal hexagon and Morse taper) and showed that the internal connections were more stable than the external connections, and Morse taper connection showed better stability and lowest torque loss after simulated year of clinical function.

(Ding et al. 2003) assessed the torque loss of two different implant-abutment internal connections following the initial tightening and demonstrated that both connections (the internal conical and octagonal groups) showed loss of torque however, this loss was significantly lower in the internal conical group than the internal octagonal group.

An in vitro laboratory study carried out by (Xia, Dandan.; Et al. 2015) to evaluate the effect of different tightening torque values on the fatigue performance of conical implant-abutment assemblies, and demonstrated that the variation of tightening torque values has significant influence on the fatigue performance of implant-abutment assemblies, as Insufficient torque will lead to poor fatigue performance of implant-abutment assemblies, It was also concluded that fatigue loading would lead to preload loss.

(Norton et al 1999). Compared the torque loss for different conical implant abutment systems after applying different tightening torque values in wet and dry environment and showed no cold welding for ITI and Astratech Morse Taper implant-abutment connection systems with tightening torque values between 20 and 40 Ncm. However when Higher tightening torque values applied (>100 Ncm), the rate of cold welding increased as well as the rate of fractures, however The environment (dry and wet) did not seem to influence these outcomes.

However an in vitro laboratory study conducted by (Prado Abraao and Pereira J. et al in 2016) to evaluate the effect of the presence of biofilms on the abutment torque loss and wear of the implant internal connection surfaces, and reported a noticeable decrease in the mean removal torque values on implant-abutment connection after immersion in a biofilm medium, and concluded that, the presence of biofilm have a lubricating effect that can decrease the friction between the contacting metal surfaces which can lead to preload loss and consequently compromise the mechanical integrity of the implant-abutment internal connections.

A very recent comparative study carried out by (Prado Abraao, et al 2017) to assess the difference in reverse torque values between Morse taper and external hexagon implant-abutment connections before and after immersion in biofilm medium, and documented that the removal torque values for External hexagon after immersion in biofilm were lower in comparison to those recorded at Morse taper implant-abutment connections, as before immersion, the removal torque values recorded for both External hexagon and Morse taper were higher than those recorded after immersion in biofilm medium.

Torque loss was also evident as a result of multiple consecutive closures using different implant-abutment connections. It was shown that when tightening and removal cycles were increased in number, there were concurrent reductions in the torque forces required for the removal of the abutment. (Ricciardi Coppede A, et al. 2009; Weiss EI, et al. 2000).

The influence of Stress/ loading on the removal torque- untightening torque value(the torque force required to remove the abutment) for different implant-abutment connection designs was studied it was shown that internal conical implant-abutment connection systems had significantly less torque loss compared to internal octagonal connection systems as well as external hexagonal connection systems. (Park JK, et al. 2010; Ricomini Filho AP, et al. 2010).

It was also demonstrated that stress/loading can cause cold welding to occur between the implant and abutment in conical systems.(Ricomini Filho AP, et al. 2010; Koutouzis T,et al. 2011; Ricciardi Coppede A, et al. 2009) Alternatively, (Piermatti J et al. 2006) showed that there was more loss of torque in the conical connection group compared to the external hexagonal or internal hexagonal groups after cycling, However, it was suggested that the screw design was an influencing factor in torque loss rather than the design of the connection itself (i.e.: the use of a screw with a thick stem and a journal appeared to provide the least loss of torque after several cycles or tightening and untightening).

B. In vivo studies:

1) Animal studies:

Four relevant in vivo studies conducted in Animals have been reviewed and included in this study; (summarised in Table V / Attachment).

(Weng et al. 2011); compared radiographically conical and non-conical implant-abutment connections in relation to marginal bone level changes for submerged and non-submerged implant and reported statistically significant differences in marginal bone level changes with less bone loss around conical connections of submerged and non-submerged implants.

(Berglundh et al 2005) compared different systems of internal cone and external hexagon in terms of marginal bone level changes and evaluated the changes radiographically with histological observation and documented less marginal bone loss for Astratech conical systems than non-conical Branemark systems. Other included studies reported either comparable or less marginal bone loss around conical connection implants (Table V / Attachment).

2) Human studies:

Four relevant in vivo comparative studies performed in Human were included in this review; (summarised in Table VI / Attachment)

Two studies conducted by Crespi et al.,(2009) and Pieri et al., (2011) compared immediately placed and loaded conical and non-conical internal implant-abutment connection system, (Crespi et al.,(2009)) reported 100% implant success for both (internal conical and external hexagon) after 2 years of function, whereas Pieri et al., (2011) reported 94% success for conical implant system and 100% success for internal hexagon after one year of function, however both researchers reported less marginal bone loss around conical implant-abutment connections than non-conical connections.

The other two studies were performed by Kielbassa et al.,(2009), and Bilhan et al., (2010) followed delayed implant placement protocols with submerged or non-submerged healing and delayed or immediate loading protocols.

Concerning implant survival and success rates, the reviewed studies showed that the survival rates for both conical and non-conical implant–abutment connection systems do not differ statistically. However, three studies reported less marginal bone level changes for conical connection systems, two out of these with a significant difference. Only one study documented higher marginal bone losses around conical implant–abutment connection systems compared to non-conical ones (Table VI /Attachment).

III. Discussion

This focused systematic literature review on the mechanical integrity and performance of Morse taper implant-abutment connection found some relevant *in vitro* and *in vivo* scientific evidence supporting the hypothesis that conical implant-abutment connections provide better performance and appear to be superior in terms of abutment fit, torque maintenance and seal performance than other connections.

In vitro laboratory studies which are summarised in tables (I, II and III) / Attachment, reported that most implant-abutment connections systems have a microgap smaller than 10 μm . Astra implants that have conical interface geometric design for instance showed The smallest microgap among all connections, followed by the Ankylos implants.(Jansen VK, et al. 1997; Baixe S, et al. 2010), given these results, the conical interface geometry appeared to provide a better performance in terms of bacterial seal, however, 100% bacterial seal couldn't be achieved. And can only happen after applying much higher torque than the recommended tightening torque values which most likely could result in cold welding and damage or distortion at the implant-abutment interface.

Testing the abutment performance under mechanical stress is the most important factor in determining the abutment stability in the long term, mechanical stress can lead to abutment micro movement and increase the size of the microgap and lead to bacterial accumulation and thus compromising the health of the peri implant tissue and consequently the longevity of the implant system. (Table III) / Attachment.

Under vertical and oblique occlusal loading, no rotational abutment movement or microgap enlargement for conical connection systems was detected. External and internal hexagonal connection systems were more prone to abutment micro movements.

Another important determining factor for the long-term implant–abutment stability is the torque maintenance between the implant and abutment following tightening. Clearly, this factor is very important as it can reduce and prevent the possibility of abutment screw loosening or movement and also microgap formation.

All tested connection systems showed torque loss following initial tightening. However, Morse taper connections showed superiority as it gained torque following initial tightening and moreover showed the lowest torque loss after loading (fatigue tests), see table III.

The Impact of the mechanical stress/loading on the torque values was clearly evidenced on non-conical implant-abutment connections, as most systems showed significant torque loss following loading, whereas Morse taper conical connection systems showed either higher resistance to torque loss or resulted in cold welding between the abutment and the implant, however no cold welding was addressed for non-conical connection implant systems, see tables (I, II and III) / Attachment.

The influence of multiple consecutive tightening and re-tightening and untightening was clearly evidenced for all connection systems, in most cases it resulted in torque loss and higher microgap size, it was shown that increasing the number of cycles lead to a significant decrease in the torque value, it was recommended that the number of cycles should be reduced in order to prevent any further torque loss and abutment loosening after insertion of the final superstructure.

One of the most important risk factors that promote the formation of microgap and can further compromise the bacterial seal performance between the abutment and implant inner surface is the loss of torque and screw loosening, as loose abutment fixtures can encourage Micro-gaps to form in the abutment/implant interface thus favouring bacterial invasion and biological and mechanical problems (Gratton DG, et al. 2001)

Most of the reviewed in vitro studies reported no 100% absolute total bacterial seal between the abutment and the implant inner surface, nevertheless, conical implant-abutment connection systems showed the best results in terms of higher bacterial seal performance.

As far as seal performance is concerned, It was recommended that using conical implant-abutment connection systems is highly favoured than non-conical connection systems as it was demonstrated that conical connections keep bacterial penetration to the minimum, furthermore, they have the highest resistance to abutment micro movement.

Concerning the outcome of the included in vivo clinical studies which were performed in animal and human (summarised in table V and VI,)/ attachment, reported that, marginal bone loss was observed for all implant systems regardless of whether the implants had been placed using a submerged or non-submerged placement protocol. Likewise, it has been shown that the placement of immediate or delayed implants (including early or late loading) had no influence on the loss of marginal bone. However, in most cases, it was demonstrated that there was less marginal bone loss around the conical connection systems in comparison to non-conical connection systems.

In spite of what have been shown and evidenced in the current reviewed literature concerning the influencing factors for the observed changes in marginal or Cristal bone height; we must acknowledge, that there are perhaps various other factors that influence marginal bone heights.

However, according to what have been evidenced in this systematic review, it would seem that conical implant-abutment connection is more advantageous as far as maintenance of marginal bone level is concerned.

Therefore the use of conical or tapered geometric abutment connection features is more preferable as it could introduce enhancements over time versus the non -conical connection systems.

IV. Conclusion

The outcome of this systematic focused review can be summarised as the following:

A. *In vitro* studies:

The design of the implant-abutment connection system appeared to be an important influencing factor in relation to the presence of microgap and torque maintenance.

Concerning abutment micro-movement and the resultant formation or generation of microgaps, it can be concluded that, conical implant-abutment connection systems are more favourable and more mechanically stable, as they seemed more reluctant to abutment micro-movement and consequently microgap enlargement than the internal and external hexagon connections as they appeared less favourable and inferior

Despite the fact that no implant-abutment connection system, currently available, has shown a 100% bacterial seal. The majority of the reviewed *in vitro* studies demonstrated that conical connection systems are more advantageous than, and appear to be superior to non-conical connections with regard to microgap size and bacterial seal, as they showed the smallest microgap size.

Concerning the maintenance of torque, it can be concluded that conical implant-abutment connections are more favourable than other non-conical connection systems, as they showed the lowest torque loss under loading, compared to other connections

B. *In vivo* studies:

Regarding implant success and survival rates (*in vivo* studies performed in human and animal) demonstrated that conical and non-conical systems are almost similar however, most cases proved that conical implant-abutment connection systems are more favourable and superior, as they showed less marginal bone loss around them.

This review suggests that using a conical implant–abutment connection systems other than non-conical implant-abutment connection, could contribute to better outcomes in terms of abutment fit, mechanical stability, and bacterial seal performance.

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VI. Attachment:

The characteristics and outcomes for the reviewed in vitro and in vivo studies are summarized in tables I ; II ; III ; IV ; V ; VI.

Table I / Seal Performance																										
The presence of Microgap and seal performance after fatigue test																										
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Used Bacteria / Dyes	Materials and Methods	Result																		
Pereira Jorge, et al. 2016	1.Morse Taper 2.External hexagon (4mm diameter)	Titamax CM, Neodent	60 implants ; 30 implants per group	Morse Taper group : 15 Ncm External Hexagon group : 32 Ncm.	To evaluate the removal torque and in vitro biofilm accumulation at Morse taper and external hexagon implant abutment connections after fatigue test in a simulated oral environment for 72 hours	<u>Human saliva</u> (10 mL) was collected from four individuals and diluted (1:5) in phosphate-buffered solution (PBS) every day over a period of 4 days then , 5 µL of the initial suspension was inoculated in brain-heart infusion (BHI) medium enriched with 5% sucrose (Sigma-Aldrich) for the biofilm growth. (to simulate actual conditions)	<ol style="list-style-type: none"> Sixty dental implants were divided into two groups: (1) 30 Morse taper and (2) 30external hexagon The samples were then immersed in 2 mL of BHI growth medium containing human saliva for 72 hours at 25°C Fatigue tests on the implant-abutment assemblies were performed at a normal force (50N) at 1.2 Hz for 500.000 cycles (to simulate fatigue over a period of 6 months of mastication.) Removal torque mean values (n = 10) were measured after fatigue tests. Groups of implant-abutment assemblies (n =8) were cross-sectioned at 90 degrees relative to the plane of the implant-abutment joints for the microgap measurement by field-emission guns scanning electron microscopy. (FEG-SEM) 	<table border="1"> <thead> <tr> <th></th> <th>RT (before fatigue)</th> <th>RT Ncm (after fatigue)</th> </tr> </thead> <tbody> <tr> <td>MT</td> <td>24 ± 0.5</td> <td>22.1 ± 0.5</td> </tr> <tr> <td>EH</td> <td>24.8 ± 0.6</td> <td>21.1 ± 0.7</td> </tr> </tbody> </table> <p>1 .Mean values of the removal torque on abutments were significantly lower for both Morse taper (22.1 ± 0.5 Ncm) and external hexagon (21.1 ± 0.7 Ncm) abutments after fatigue tests than those recorded without fatigue tests (respectively, 24 ± 0.5 Ncm and 24.8 ± 0.6 Ncm)</p> <table border="1"> <thead> <tr> <th></th> <th>Microgap (before fatigue) µm</th> <th>Microgap (after fatigue)</th> </tr> </thead> <tbody> <tr> <td>MT</td> <td>1.7 ± 0.4</td> <td>3.2 ± 0.8</td> </tr> <tr> <td>EH</td> <td>1.5 ± 0.4</td> <td>8.1 ± 1.7</td> </tr> </tbody> </table> <p>2-Mean values of microgap size for the Morse taper joints were statistically significantly lower without fatigue tests (1.7 ± 0.4 µm) than those recorded after fatigue tests (3.2 ± 0.8 µm). 3-mean values of microgap size for external hexagon joints free of fatigue were statistically significantly lower (1.5 ± 0.4 µm) than those recorded after fatigue tests (8.1 ± 1.7 µm) (P < .05). -Conclusion: The mean values of removal torque loss, microgap size, and biofilm density recorded at Morse taper joints were lower in comparison to those recorded at external hexagon implant-abutment joints after fatigue tests in a simulated oral environment for 72 hours</p>		RT (before fatigue)	RT Ncm (after fatigue)	MT	24 ± 0.5	22.1 ± 0.5	EH	24.8 ± 0.6	21.1 ± 0.7		Microgap (before fatigue) µm	Microgap (after fatigue)	MT	1.7 ± 0.4	3.2 ± 0.8	EH	1.5 ± 0.4	8.1 ± 1.7
	RT (before fatigue)	RT Ncm (after fatigue)																								
MT	24 ± 0.5	22.1 ± 0.5																								
EH	24.8 ± 0.6	21.1 ± 0.7																								
	Microgap (before fatigue) µm	Microgap (after fatigue)																								
MT	1.7 ± 0.4	3.2 ± 0.8																								
EH	1.5 ± 0.4	8.1 ± 1.7																								

Table I / Seal Performance								
The effect of different tightening torque values on the seal performance								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Used Bacteria / Dyes	Materials and Methods	Result
GEHRKE, Sergio Alexandre et al. 2015	Morse taper solid abutments at 11 degrees wall inclination , 4 mm in diameter	Not specified	40 implants, 10 implant per group	Group 1: 25 Ncm Group 2: 30Ncm Group 3: 35 Ncm Group 4: 40Ncm	To assess the fit of the implant- abutment interface by the metallographic technique and by scanning electron microscopy (SEM) at different torque levels	N.A.	<ol style="list-style-type: none"> 1. 40 dental implants with 40 straight solid abutments were divided into 4 groups of 10, each group of abutments were tightened at different insertion torque values, 2. to limit the effect of sedimentation on the screws, which leads to preload reductions, the components were retightened with the respective torque values 10 minutes after the initial torque was applied 3. all samples were embedded in metallographic epoxy resin and sectioned longitudinally with a diamond disc, 4.the slices were then polished , washed , dried and metalized with gold 5. The samples were analyzed under a scanning electron microscope SEM 6. Data collection Three measures (L1, L2 and L3) were obtained from each picture at a magnification of 5000 x; the first one from the center (L2), and the other two 10 µm away from the first; and averages were generated for each position (<p>The overall mean gap and standard deviation were as follows:</p> <ol style="list-style-type: none"> 1. for group g1($9.0 \pm 1.36 \mu\text{m}$) 2. group g2($7.9 \pm 2.81 \mu\text{m}$) 3. group g3 ($2.0 \pm 0.76 \mu\text{m}$) 4. group g4 ($0.3 \pm 0.40 \mu\text{m}$) <ul style="list-style-type: none"> • The linear area of contact between the abutment and the implant increased as torque augmented • This study demonstrated that higher insertion torque values in a conical internal connection increase the fit (contact) of the implant-abutment interface • The results obtained in this study, indicate that 35 Ncm was the best torque value for this type of conical internal connection (cone with 11°).

Table I / Seal Performance*Continued*

Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Used Bacteria / Dyes	Materials and Methods	Result
Blum, Kai et al , 2015	Morse taper specifications: (Implant diameter/ length; Cone angle) Ankylos: (4.5/11;5.7) Astra: (4.5/11;10.9) Noble Active: (4.3/11.5;11.7) Bone Level: (4.1/12;15)	1.Noble Active (NA), 2.Ankylos CX (AN); 3.Bone Level (BL); 4.Astra OsseoSpeed™ (AS)	32 implants ; 4 groups / 8 implants per group	system-specific torque recommended by the manufacturers	To analyse and visualize the microgap size after cyclic loading and the wear pattern with regard to the Implant-Abutment Connection (IAC)design. Using, synchrotron micro-tomography SRX (CT)	N a.	<ul style="list-style-type: none"> • 4 conical implant systems with different conical implant–abutment interfaces were first evaluated using synchrotron X-ray high-resolution radiography (SRX) and scanning electron microscopy (SEM). • All implants were then embedded to the implant shoulder of a computer-controlled dual axis-chewing simulator then subjected to cyclic loading at 98 N (10 Kg. at 2 Hz.) to an angle of 30 degrees to the vertical axis, • Their microgap was evaluated after 100,000, 200,000 and 1 million cycles using SRX, synchrotron micro-tomography (CT). • Wear mechanisms of the implant–abutment connection (IAC) after 200,000 cycles and 1 million cycles were further characterized using SEM. 	<ul style="list-style-type: none"> • All implants exhibit a microgap ranging from 0.1–0.14 nm) in the coronal part of the IAC and 1.2 nm(range 0.12–5.0 μm) in the lower part of the IAC between the implant and abutment prior to loading. • The gap size increased with cyclic loading with its changes being significantly higher within the first 200,000 cycles. • Wear was seen in all implants regardless of their interface design. The wear pattern comprised adhesive wear and fretting. • Wear behaviour changed when a different mounting medium was used (brass vs. polymer).

Table I / Seal Performance								
/ Bacterial leakage <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Used Bacteria / Dyes	Materials and Methods	Result
D'Ercole, Slimonetta et al , 2014	Morse Taper	Oralplant ; Cordenons, PD, Italy	30, 10 implants per group	Group1: 20N Group2: 30N Group3: 40N	To assess whether there was a decrease of Bacterial leakage with increasing torque values in conical Morse cone connection implants	Pseudomonas aeruginosa suspension incubated for 24 hours at 37°C ; Aggregatibacter actinomycetemcomitans incubated for 48 hours at 37°C in 5% CO ₂	A total of 30 Morse taper implants divided in to 3 groups(10 implants each), G1 abutments were connected to the implants with 20N, G2 with 30N, G3 with 40N, each group was later subdivided into two groups of 5 implants which were then inoculated with 2 different bacterial suspensions and monitored for 14 days	<u>Bacterial contamination</u> <ul style="list-style-type: none"> • In group 1 (20 N), was found in 2 of the 5 implant-abutment assemblies seeded with the P. aeruginosa, all on the sixth day • in group 2 , Two assemblies at 30N and inoculated with P. aeruginosa showed the evidence of bacterial leakage after 13 days of incubation • In tgroups 1,2 and3 he assemblies at 20 N ,30 and 40 N seeded with A. actinomycetemcomitans, no contamination was found. -In groups 1 and 2 , bacterial contamination was found in 2 of the 10 implants, only in the specimens seeded with P, aeruginosa . -In group 3 , no contaminated samples were found.
Nascimento et al., 2012	Morse taper, internal and external hex	SIN, Sistema de Implante Nacional	20 per group, 10 loaded and 10 unloaded	According to the recommendation of the manufacturer (20 Ncm)	Saliva leakage into the implant–abutment interface under loaded and unloaded conditions	Human saliva	Implant abutment connection and incubation in human saliva. Detecting saliva leakage. Half of the specimens: Cycling with 120 N, 500,000 cycles at 1.8 Hz	Contamination: External hex: Loaded 10 out of 10, unloaded 3 out of 10 Internal hex: Loaded 10 out of 10, unloaded 4 out of 10, Morse taper: Loaded 9 out of 10, unloaded 1 out of 10

Table I / Seal Performance*continued*

Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Used Bacteria / Dyes	Materials and Methods	Result
Tripodi et al., 2012	Internal cone, internal hex	Universal II HI and CM, (Implacil De Bortoli)	10 per group, 5 per bacterial species	According to the recommendation of the manufacturer	Bacterial leakage from the implant–abutment interface	<i>P. aeruginosa</i> (PS), <i>A. actinomycete mcomitans</i> (AA)	Bacterial inoculation of the implant and abutment connection and detecting bacterial leakage	For PS inoculation: 2 out of 5 in the conical group and 2 out of 5 in the internal hex group, for AA: 0 out of five in the conical and 3 out of 5 in the internal hex group
Assenza et al., 2011	Internal cone, internal trilobed, cemented	Ankylos (Dentsply Friadent), Replace Select (Nobel Biocare), Bone System	10 per system	According to the recommendation of the manufacture	Bacterial leakage from the implant-abutment interface	<i>P. aeruginosa</i> , <i>A. actinomycete mcomitans</i>	Bacterial inoculation of the implant and abutment connection, and measuring bacterial leakage	Bacterial leakage: internal conical 1 out of 10, Internal trilobed 6 out of 10, cemented 0 out of 10

Table I Seal Performance									
<i>continued</i>									
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Used Bacteria / Dyes	Materials and Methods	Result
Teixeira et al., 2011	Internal cone, internal hex	Titamax CM, Titamax II Plus (Neodent)	20 per system (10 per experiment)	Titamax II Plus 20 Ncm, Titamax CM 32 Ncm, (recommended by the manufacturer)	Bacterial leakage into the implantabutment interface	Bacterial leakage from the implant-abutment interface	S. aureus	1. Bacterial contamination before and 2. after implant-abutment connection, incubation and colony growth calculation	Into: Conical 70% and internal hex 100% leakage. From: Conical 77.7% and internal hex 100% leakage
Koutouzis et al., 2011	Internal cone, four groove internal cone	Ankylos (Dentsply Friadent), Bone level (ITI Straumann)	14 per system	Ankylos 25 Ncm, Bone level 35 Ncm, (recommended by the manufacturer)	Bacterial leakage into the implant abutment interface during loading	Torque value loss after loading	E. coli	Implant abutment connection, loading in E. coli medium, disconnection measuring loosening torque, incubation and measuring CFUs	Ankylos: 1 out of 14, mean CFUs 14.07652.56, torque increase (2.8563.23 Ncm), Bone level (ITI): 12 out of 14, mean CFUs 184.646242.32, torque decrease (-5.0062.77 Ncm)
Ricomini Filho et al., 2010	Internal cone 1 (one piece), internal cone 2 (two pieces), external hex, locking taper	Not mentioned	11 per system (6 with and 5 without loading)	Morse Taper 1: 35 Ncm, Morse Taper 2 and external hexagonal: 15 Ncm, (recommended by the manufacturer)	Bacterial leakage into the implant abutment interface Subjected to thermal cycling and mechanical fatigue	Preload loss after thermal cycling and mechanical fatigue	S. sanguinis	Connection, thermal cycling and mechanical fatigue testing, sterilization and contamination to bacterial medium, detorque measurements and SEM analysis	Bacterial leakage after loading: Morse Taper 1 (67%), Morse Taper 2 (50%), external hexagonal (0%), locking taper (60%) Preload loss after cycling: Morse Taper 1 (12.5%), Morse Taper 2 (-23.3%), External hexagonal (-23.1%).

Table I / Seal Performance*continued*

Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Used Bacteria / Dyes	Materials and Methods	Result
Aloise et al., 2010	Internal cone, internal cone	Bicon Implant System (Bicon), Ankylos (Dentsply Friadent)	10 per system	Ankylos 25 Ncm, Bicon tapped, (recommended by the manufacturer)	Bacterial leakage from the implant-abutment interface.	N.a.	S. sanguinis	Inoculation S. sanguinis, connecting abutment and implant, incubation and proof of bacterial presence or absence	Bacterial leakage: Ankylos 20%, Bicon 20%.
Harder et al., 2010	Internal cone, internal cone	OsseoSpeed (AstraTech), Ankylos (Dentsply Friadent)	8 per system	According to the recommendation of the manufacturer	Molecular leakage of endotoxin along the implant abutment interface	N.a.	LPS of Salmonella enterica	Inoculation of implant with LPS, connection to abutment and incubation, endotoxin detection and measuring concentration over time (168h)	Endotoxin detection in both groups after 5 minutes. Significant less endotoxin concentration (mean) for OsseoSpeed units over the whole examination period
Baixé et al., 2010	Internal cone (2x), external flat, internal flat	Ankylos (Dentsply Friadent), OsseoSpeed (Astratech), Standard ITI (ITI Straumann, Nobel Replace Tapered Groovy (Nobel Biocare)	5 per system	Nobel 35 Ncm, ITI 15 Ncm, Astra 25 Ncm, Ankylos 15 Ncm (recommended by the manufacturer)	Microgap between implant and abutment	Microgap comparing titanium and zirconia abutments	N.a.	Longitudinal cutting and scanning electron microscopy (SEM)	The mean microgap was larger for flat-to-flat interface systems compared to conical interface systems, zirconia abutments showed smaller microgaps than titanium abutments

Table I / Seal Performance									
<i>continued</i>									
Author/ Year	Abutment connection	System	Specimens Number	tightening torque	Primary objective	Sec. objective	Used Bacteria / Dyes	Materials and Methods	Result
Tesmer et al., 2009	Internal cone, manipulated internal cone, trichannel internal connection	Ankylos and manipulated Ankylos (Dentsply Friadent), Nobel Replace Select (Nobel Biocare)	10 per system	Ankylos and manipulated Ankylos 25 Ncm, Nobel Replace Select 35 Ncm, (recommended by the manufacturer)	Bacterial invasion into the implant abutment interface	N.a.	A. actinomycete mcomitas, P. gingivalis	Implant abutment connection, contamination with bacterial solution (Aa and Pg), disconnection, incubation and detecting bacterial contamination	Bacterial contamination Ankylos: (Aa 3/10, Pg 0/ 10, median CFUs; Aa 0, Pg 0), Nobel Replace select: (Aa 9/10, Pg 9/ 10, CFUs; Aa 24.5, Pg 12), Manipulated Ankylos: (Aa 10/ 10, Pg 10/10, CFUs; Aa 81, Pg 55)
Coelho et al., 2008	Internal cone, trilobed internal, internal hex	Standard SLA implant (ITI, Straumann), Replace Select (Nobel Biocare), Intralock short collar implant (Intra-lock Int.)	5 per system	According to the recommendation of the manufacture	Sealing capability of implant system	N.a.	Toluidin Blue dye	Contamination of implant interface, connection to abutment and measuring dye leakage over time with spectrophotometric analysis	Total release after 144h: ITI Straumann 55%, Intra-lock 22% and Replace Select 100%.

Table I / Seal Performance									
<i>continued</i>									
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Used Bacteria / Dyes	Materials and Methods	Result
Gross et al., 1999	Internal cone, external hex (2x), spline connection	ITI (Straumann), 3i, CeraOne and Steri-Oss (Nobel Biocare), Spline (Sulzer Calcitek),	3 per system (1 per torque group)	10 Ncm, 20 Ncm and according to the recommendation of the manufacturer	Dye leakage over time	N.a.	Gentian violet dye	Contamination of implant interface, connection to abutment and measuring dye leakage over time with spectrophotometric analysis	Leakage increased in all systems over time with no significant differences after 80 minutes, Leakage decreased significantly <u>as tightening torque increased to recommended values</u>
Jansen et al., 1997	Internal cone (3x), div. external flat (7x), flat 1 internal cone, flat 1 internal silicon washer	OsseoSpeed (Astratech), Ankylos, Frialit-2, IMZ (Dentsply Friadent), Bonefit conical and synOcta (ITI Straumann), Branemark (Nobel Biocare), Semados (Bego Semados), HaTi (Ledermann), Calcitek Implants	10 per system	According to the recommendation of the manufacturer	Bacterial seal from implant-abutment interface	Microgap between implant and abutment	E. coli	Bacterial inoculation of the inner part of the implant, abutment connection, cultivation and detection of bacterial leakage over time (14 days), microgap detection with SEM	All systems showed bacterial leakage of the implant abutment interface after 5 days, the micro gap was less than 10 µm in all systems, <u>conical connection systems showed the smallest micro gap</u>

Author/Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective Sec. objective	Used Bacteria / Dyes	Materials and Methods	Result														
Prado Abraao ; Pereira J., et al(2017)	Morse Taper(M T) (4.5 × 4 × 1.5 mm) External hexagon (EH) (4.5 × 4 × 1 mm)	Titamax, Neodent ® Curitiba, Brazil	40 specimens;20 per group 1. 20 for MT group , which was further subdivided in to two groups of 10; (A) Morse taper free of medium containing Biofilm (B) after contact with a medium containing biofilm from human saliva . 2. 20 for EH group: (C) 10 EH free of medium containing biofilm, (D) 10 EH ,after contact with medium containing biofilm from human saliva	Morse taper abutments: <u>15 Ncm</u> External hexagon abutments: <u>32 Ncm</u> according to the manufacturer’s recommendations	to evaluate the removal torque values on abutments and the morphological wear aspects of two different dental implant joints after immersion in a medium containing biofilm from human saliva.	<u>Human saliva</u> 5 ul. Diluted human saliva that was incubated at 37° c under microaerophilic conditions (5% CO ₂) for 72 hours.	<ol style="list-style-type: none"> At first, the 40 implants were placed in a metallic holding device and the corresponding abutments were firstly torqued to the implants according to the manufacturer’s recommendations, using a handheld torque meter The implant-abutment assemblies were divided into four groups (n = 10): (A) Morse taper free of a medium containing biofilm, and (B) after immersion in a medium containing biofilm from human saliva Evaluation of the removal torque; Abutments from group A and C (n = 10) were evaluated after 72 h from recording the initial torque, After biofilm growth for 72 h, the removal torque values were measured for groups B and D The samples were then analysed by scanning electron microscopy, SEM MT implants were cross sectioned to assess the implant inner surfaces by optical profilometry 	<p><u>Evaluation of the removal torque</u></p> <table border="1"> <thead> <tr> <th>Group</th> <th>Mean RT (Ncm)</th> </tr> </thead> <tbody> <tr> <td>EH-Initial</td> <td>32</td> </tr> <tr> <td>EH-C</td> <td>27</td> </tr> <tr> <td>EH-D</td> <td>24.82</td> </tr> <tr> <td>MT-initial</td> <td>15</td> </tr> <tr> <td>MT-A</td> <td>24.32</td> </tr> <tr> <td>MT-B</td> <td>23</td> </tr> </tbody> </table> <ul style="list-style-type: none"> On groups A and B (Morse taper), the RT values were higher than those of the initial torque as seen in Table There was an increase of 62.13% in RT values on group A and of 53.33% recorded for group B The values for groups C and D (EH implants) included lower RT values compared to the IT. There was a decrease of 15.6% in RT values on group C and 22.4% on group D Both implant-abutment assemblies (EH&MT) in contact with medium containing biofilms (groups B and D) had lower RT values than the samples free of medium containing biofilms (groups A and C). <u>Ra and Rt roughness values</u> <u>for group A (free of medium containing biofilm from</u> 	Group	Mean RT (Ncm)	EH- Initial	32	EH-C	27	EH-D	24.82	MT-initial	15	MT-A	24.32	MT-B	23
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								<p><u>human saliva) were higher than those obtained before tightening.</u></p> <ul style="list-style-type: none">• <u>Regarding the group tested in contact with the biofilm (group B), Ra and Rt values were statistically lower than those in group A</u>
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Table II / The Mechanical integrity									
The effect of Biofilm on the removal torque									
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objectiv e	Used Bacteria / Dyes	Materials and Methods	Result
Prado Abraao; Pereira J., et al.(2016)	Morse taper (4.5 ×4 × 1.5mm)	Titamax CM (Neodent)	10 implants: Group A:: at room temperature Group B : after immersion in biofilm medium	15 Ncm	To evaluate the effect of biofilms on the abutment torque loss and wear of implant internal connection surfaces	N.A.	<u>Human saliva</u> 5 ul. Diluted human saliva that was incubated at 37° c under microaerophil ic conditions (5% CO ₂) for 72 hours.	10 Morse taper implant systems were assessed 1. The abutments were tightened to the dental implants by torque application at 15 Ncm 2. They were then placed in 24 well plates containing 2 ml. brain heart infusion BHI medium and 5 ul. Diluted human saliva that was incubated at 37° c under microaerophilic conditions (5% CO ₂) for 72 hours. 3. After removal torque evaluation, the abutments were removed to evaluate the morphologic aspects of the implant internal connection surfaces 4. The samples were then analysed by scanning electron microscopy (SEM) 5. MT implants were cross sectioned to assess the implant inner surfaces by optical profilometry.	1. Mean removal torque values were statistically lower among the implant-abutment assemblies that had contact with biofilms(group B) than those that were free from biofilms (group A) 2. Plastic deformation and abrasion marks on the inner implant surfaces were detected by SEM analysis

Table II / The Mechanical integrity																											
Stress/ loading Performance																											
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result																				
Xia. Dandan. Et al. (2015)	tapered, 13 mm in length and 3.7 mm at the neck, with 20°-angle abutments.	Zimmer Dental, Carlsbad, CA, USA	30 implant Divided into 3 groups, 10 implants per group	Group1: 24Ncm (less than recommended torque) Group2: recommended torque, <u>30 Ncm</u> Group3 more than recommended torque, <u>36 Ncm</u> :	to evaluate the effect of different tightening torque values on the fatigue performance of implant-abutment assemblies . Meanwhile, the other objective was to investigate the effect of fatigue loading on abutment screw reverse torque values .	<ol style="list-style-type: none"> 1- Thirty implant-abutment assemblies were divided into 3 groups of 10 implants each 2- were randomly assigned to three tightening groups {g1(24Ncm);g2(30Ncm); g3(36Ncm)} 3- Five implant-abutment assemblies from each group were randomly selected to constitute the control group; they were unscrewed, and their reverse torque(RT) values recorded. 4- The remaining specimens were subjected to fatigue tests 5- A compressive cyclic sine wave load between 30 N and 300 N at a loading frequency of 15 Hz (far away from the recommendations)was applied to the remaining specimens for 5×10⁶ cycles, or until failure 6- After the fatigue tests, the residual reverse torque (RRT)values were recorded if available 7- A scanning electron microscope was used to observe the fractured surfaces of specimens. Prior to insertion to the Scanning electron microscope (SEM), the fractured surfaces were coated with a thin layer of gold 	<ol style="list-style-type: none"> 1. In the 24 Ncm tightening group, all the implant and abutment screws fractured at the root of the first outer thread of the implant 2. <table border="1" style="margin-left: 20px;"> <thead> <tr> <th colspan="4">Average values of RT and RRT</th> </tr> <tr> <th>Tightening Torque (Ncm)</th> <th>RT (NCM)</th> <th>RRT (NCM)</th> <th>P</th> </tr> </thead> <tbody> <tr> <td>24</td> <td>21.74</td> <td>-</td> <td>-</td> </tr> <tr> <td>30</td> <td>27.48</td> <td>21.08</td> <td><0.05</td> </tr> <tr> <td>36</td> <td>31.88</td> <td>27.74</td> <td><0.05</td> </tr> </tbody> </table> <ul style="list-style-type: none"> • The 24 Ncm tightening torque exhibited a 9.42% torque loss without loading. • The 30 Ncm group showed 8.40% torque loss without loading and 29.73% torque loss after loading • The 36 Ncm group showed a 11.44% torque loss without loading while 22.94% torque loss after loading. • It was demonstrated that the variation of tightening torque value has significant influence on the fatigue performance of implant-abutment assemblies • Insufficient torque will lead to poor fatigue performance of implant-abutment assemblies, and the abutment screws should be tightened to the torque recommended by the manufacturer in order to prevent mechanical complications • reverse torque values of specimens after fatigue loading declined. It was also concluded that fatigue loading would lead to preload loss. 	Average values of RT and RRT				Tightening Torque (Ncm)	RT (NCM)	RRT (NCM)	P	24	21.74	-	-	30	27.48	21.08	<0.05	36	31.88	27.74	<0.05
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Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result																																				
Shin Mo Hyon, et al. (2014)	(Regular and wide-diameter implant systems) 1.External butt joint, (EH) 2.A one-stage internal cone,(MT) 3. two-stage internal Cone(MT)	All from Osstem implant (Osstem, pussan,Korea)	35 implants; divided into 7 groups , 35 per system , 5 per experiment	a. 30 Ncm was applied to each abutment screw Ten minutes later, the same tightening torque was applied again After 10 000 cycles , the same tightening torque was applied for the simulation of more actual clinical situations	to investigate the effect of the implant-abutment connection design and diameter on the screw joint stability in implant systems with a two-stage external butt joint and one- and two-stage internal cones by comparing the removal torque loss of the abutment screw <u>after repeated loads</u>	1. a total of seven groups according to the abutment- fixture connection type and diameter, including platform-switching type samples that used a regular abutment in their fixture with a wide diameter in the USII system 2. 30 Ncm tightening torque was applied to each abutment screw using a digital torque gauge Ten minutes later, the same tightening torque was applied again to compensate for the preload loss due to the surface sinking 3. Then the removal torque of each abutment screw was measured using a digital torque gauge Then, a machined stainless steel metal tube with disc shape was attached to abutments using a resin class temporary cement 4. A sine-type repeated load with a maximum 150 N , a minimum 10 N, and a 10 Hz cycle was applied to the metal tube, 5 mm away from the center axis of the implant 5. Then, 10 ⁴ cycles and a 30 Ncm tightening torque were applied again for the simulation of more actual clinical situations.	1 Mean value ± SD of the initial and postload removal torques (Ncm) <table border="1"> <thead> <tr> <th>Group</th> <th>Initial reverse Torque</th> <th>Postload Removal torque</th> </tr> </thead> <tbody> <tr> <td>1 Reg.EH</td> <td>26.0 ± 0.8^{abc}</td> <td>24.6 ± 1.5C</td> </tr> <tr> <td>2 Wide EH</td> <td>28.3 ± 1.4^c</td> <td>25.6 ± 1.6C</td> </tr> <tr> <td>3 T-wide EH</td> <td>26.5 ± 1.4^{abc}</td> <td>24.2 ± 0.7C</td> </tr> <tr> <td>4 Reg, MT</td> <td>25.1 ± 1.1^{ab}</td> <td>20.8 ± 0.7B</td> </tr> <tr> <td>5 wide MT</td> <td>26.8 ± 0.4^{bc}</td> <td>19.5 ± 2.6B</td> </tr> <tr> <td>6 Stan. MT</td> <td>24.8 ± 0.9^{ab}</td> <td>12.5 ± 0.6A</td> </tr> <tr> <td>7 Stan. MT</td> <td>24.1 ± 0.9^a</td> <td>15.6 ± 1.1A</td> </tr> </tbody> </table> <p>1. The initial removal torque was higher in Group II than in Group VII (P<.05), and no significant difference was found among the other groups (P>.05) 2. The postload removal torque was highest to lowest in the regular-diameter comparison (P<.05) in the following groups, in this order: VI, IV, and I 2. Mean rate ± SD of the postload removal torque loss (%)</p> <table border="1"> <thead> <tr> <th>Group</th> <th>Torque loss%</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>5.4 ± 3.4a</td> </tr> <tr> <td>2</td> <td>9.3 ± 7.8a</td> </tr> <tr> <td>3</td> <td>8.3 ± 4.0a</td> </tr> <tr> <td>4</td> <td>17.2 ± 4.8ab</td> </tr> <tr> <td>5</td> <td>27.0 ± 10.5bc</td> </tr> </tbody> </table>	Group	Initial reverse Torque	Postload Removal torque	1 Reg.EH	26.0 ± 0.8 ^{abc}	24.6 ± 1.5C	2 Wide EH	28.3 ± 1.4 ^c	25.6 ± 1.6C	3 T-wide EH	26.5 ± 1.4 ^{abc}	24.2 ± 0.7C	4 Reg, MT	25.1 ± 1.1 ^{ab}	20.8 ± 0.7B	5 wide MT	26.8 ± 0.4 ^{bc}	19.5 ± 2.6B	6 Stan. MT	24.8 ± 0.9 ^{ab}	12.5 ± 0.6A	7 Stan. MT	24.1 ± 0.9 ^a	15.6 ± 1.1A	Group	Torque loss%	1	5.4 ± 3.4a	2	9.3 ± 7.8a	3	8.3 ± 4.0a	4	17.2 ± 4.8ab	5	27.0 ± 10.5bc
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6	GSII standard	4.0mm 11° Morse taper	2.5mm hex																																								
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					<p>6. 10⁵ cycles of repeated load were applied, and the removal torque was measured using a digital torque gauge. The removal torque loss was calculated according to the following formula. <u>Postload Removal Torque Loss (%) = [(Initial Removal Torque Value – Postload Removal Torque value) / Initial Removal Torque Value] × 100</u></p>	<p>6 49.4 ± 2.9d</p> <p>7 35.2 ± 5.3cd</p> <p>1. For the regular diameter, the postload removal torque loss was higher in Group VI(MT) than in Groups I(EH) and IV (P<.05),</p> <p>2. For the wide diameter, the removal torque loss was higher in Groups V and VII than in Group II (P<.05), but no significant difference was found between Group V and Group VII (P>.05).</p> <p>3. In the comparison of the implant diameters, the postload removal torque loss was higher in Group VI than in Group VII (P<.05), but no significant difference in the removal torque loss was found among the other groups (P>.05).</p> <p>4. there was no significant difference between Group III and Group II in the USII system (P>.05).</p>
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Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result												
Pinheiro Feitosa Paulo Cesar et al. 2013	(Universal abutments anti-rotational (Tilite) with a diameter of 4.3 mm and a titanium screw) were used for the: 1.External hexagon, 2.Internal hexagon, and 3. Morse taper	Neodent, Curitiba, Parana, Brazil	30 Implants : 10 per group 1. Group EH (external hexagon) – Alvim Ti 2. group IH (internal hexagon) – Alvim II Plus 3. group MT (Morse taper) – CM Alvim	Two torques of 20 Ncm (according to the manufacturer) were applied, within 10 mins. Break between them	The objective of this study was to compare the torque(T0)and detorque(T1) values of screw intermediates of external hexagon, internal hexagon, and Morse taper implants in single restorations before and after mechanical cyclic	<ol style="list-style-type: none"> The three groups:(Group EH; Group IH; Group MT) were embedded in an epoxy resin– glass fiber composite which has an appropriate elastic modulus (approximately 20 GPa) similar to bone and is sufficiently tough to allow cyclic testing two torques of the same value (20 N cm, according to the manufacturer) were applied, with a 10-min break between them After 2 min of the second torque, the value of initial detorque (T0) was measured and recorded The samples underwent cyclic mechanical testing whereby 400 N of axial force was applied over a crown surface at a frequency of 8 Hz for a total of 1 million cycles; this process simulated a year of implant function. After the fatigue test, the samples were set on the torque meter to measure and record the final detorque value(T1) 	<ol style="list-style-type: none"> Table shows the average initial detorque (T0) and final detorque (T1) values of the groups: <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Group</th> <th>Torque (T0)</th> <th>Detorque (T1)</th> </tr> </thead> <tbody> <tr> <td>EH</td> <td>12.80±2.86Ncm</td> <td>10.40±0.55Ncm</td> </tr> <tr> <td>IH</td> <td>15.40±2.07Ncm</td> <td>13.80±1.30Ncm</td> </tr> <tr> <td>MT</td> <td>18.60±0.89Ncm</td> <td>19.40±0.55Ncm</td> </tr> </tbody> </table> There was no statistically significant differences between the values of T0 and T1 of the intra-group samples A statistically significant difference in T0 was found between the EH and MT groups (P = 0.012). The MT group obtained higher T0 values than the EH group, and the IH group obtained intermediate values of T0 without statistical difference The T1 means showed that the MT group obtained the highest values followed by the IH and EH groups, which had the lowest values of T1 (P = 0.001) 	Group	Torque (T0)	Detorque (T1)	EH	12.80±2.86 Ncm	10.40±0.55 Ncm	IH	15.40±2.07 Ncm	13.80±1.30 Ncm	MT	18.60±0.89 Ncm	19.40±0.55 Ncm
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Table II / The Mechanical integrity								
Stress/ loading Performance <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Secondary objective	Materials and Methods	Result
Seetoh et al., 2011	Internal cone, internal hex1 cone, internal four groove1 cone	Ankylos (Dentsply Friadent), Lifecore PrimaConn ex (Keystone Dental), Bone Level (ITI Straumann)	10 per system, 5 per group (titanium (Ti) and zirconia (Zr) abutments)	According to the recommendation of the manufacturer	Load fatigue performance/ resistance of different implant abutment connection systems	Fatigue performance of Ti and Zr abutments and determine failure mode and region	Fatigue loading until failure of the implant abutment specimens or maximal cycles (10 Hz, 5 3 10 ⁶ cycles). SEM analysis of fracture region	No significant difference between the Ti abutments tested for the three systems. Straumann Zr abutments showed significant better load fatigue resistance than Ankylos and Prima-Connex implantsabutment systems.
Cehreli et al., 2004	Internal cone, internal octagon	ITI Solid and Syn-Octa implants (ITI Straumann)	8	35 Ncm (recommended by the manufacturer)	Load fatigue performance/ resistance of different implant abutment connection systems	Tightening torque loss after loading	Fatigue loading (500,000 cycles, Periotest value (PTVs) measurements after every 100,000 cycles), after termination removal torque value (RTV) measurement	Solid abutments showed significant higher RTVs than synOcta abutments, both implant abutment connections showed comparable high fatigue resistances

Table II / The Mechanical integrity								
Tightening / loosening torque, cold welding								
Author/ Year	Abutment connection	System	Specimens Number	tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Park et al., 2010	Internal cone, internal cone1 external colar, external hex	Osstem Implant Systems (US II, SS II, GS II)	10 per system, 5 per group (titanium and tungsten carbide carbon coated titanium abutments)	30 Ncm	Compression force and tightening abutment to implant and screw removal torque before and after cycling	N.a.	Measuring compression force and tightening and removal torque before and after loading (106 cycles).	All systems showed preload loss after initial tightening. External hexagonal connection showed significantly higher preload loss after loading than the two conical connections
Richiardi Copedde et al., 2009	Internal cone, internal cone	Alvim CM implants and Universal abutment CM oneand two-piece (Neodent)	34 per implantabutment system, 17 per group (loading and no loading)	20 Ncm solid abutment, 10 Ncm two-piece abutment (recommended by the manufacturer)	Effect of loading on the abutment removal torque	Effect of repeated insertion/ removal cycles on the abutment removal torque	Measuring removal torque after repeated insertion/ removal and after loading (1,325 cycles), SEM	Loading increased removal torque; two piece system had to be removed in two steps with torque gain of the second piece after loading (cold welding); increasing number of abutment insertion/removal decreased removal torque values
Piermatti et al., 2006	Internal cone, external hex (2x), internal Hex + cone	OsseoSpeed (Astratech), Bio-Lok (Bio-Lok), Branemark (Nobel Biocare), Screw-vent (Zimmer Dental)	10	32 Ncm	Removal torque in combination with loading	N.a.	Off axis loading of the specimens and recording removal torque every 250.000 cycles up to 106 cycles	Astra showed significant higher torque loss than other systems under loading conditions, screw design seems to be an important factor influencing the loosening torque

Table II / The Mechanical integrity								
Stress/ loading Performance <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Ding et al., 2003	Internal cone, internal octagon	Standard and syn- Octa ITI (ITI Straumann)	12 ITI standard, 24 synOcta (12 with solid and 12 with synOcta abutment)	35 Ncm (recommended by the manufacturer)	Repeated torque/ reverse torque values of each system and implant- abutment combination	Maximal failure load	Measuring repeated in/ out torque values and maximal bending moment, SEM	Initial removal torque of solid abutments combined with standard and syn- Octa implants were significantly higher than the initial torque removal of the synOcta implant abutment, solid abutments with both implant types showed significant higher load resistance
Norton et al., 1999	Internal cone, internal cone, internal cone	Astratech (diameters 3.5 and 5.0), standard ITI (ITI Straumann)	5 for Astra, 4 for ITI	Group 1: low torque (4-50 Ncm), Group 2: high torque (100- 300 Ncm)	Torque loss after different tightening torques <u>in wet</u> <u>and</u> <u>dry</u> environment for different implant- abutment connections	N.a.	Measuring different tightening and the resulting removal torques in wet and dry environments	All combination showed comparable removal torques in wet and dry environments; cold welding did not occur between 20 and 40 Ncm; <u>surface area of</u> <u>interface seems to</u> <u>influence torque</u> <u>loss</u>

Table III / stress/ loading performance								
Bending moment/ maximal load resistance								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque		Primary objective	Materials and Methods	Result
Marc Philipp Dittmer. Et al. (2012)	Internal conical interface/hex agon Butt-joint Internal conical interface/no index Internal conical interface/octa gon	Astra AST OsseoSpeed; Bego BEG Semados Ø 4.5/13 mm; Camlog CAM Screw- line promote plus Ø 4.3/13 mm; Friadent FRI Ankylos plus B14 Ø 4.5/14 mm; Nobel Biocare NOB; Straumann STR Standard implant Ø 4.1 RN/14 mm	60 implants with different interface design, from 6 different systems , 10 implants per system	Astra	25Ncm	to evaluate differently designed implant– abutment assemblies with respect to the yield forces before and after cyclic fatigue using a static overload test	1. Ten implants per type were embedded with polyurethane resin, Abutments were fixed to the implants by the corresponding screws, with the torque given by the manufacturer 2. The 10 specimens of each type were divided into two homogeneous groups: one half was tested for static loadbearing capacity without any further treatment (cont) 3. the other one underwent one million cycles of mechanical loading in a chewing simulator 4. with 100 N as the upper load limit at a frequency of 2 Hz prior to final testing (dyn) Since a survey revealed that the average number of chewing cycles is about 800,000 per year [24], the one million cycles applied in this study corresponded to an in vivo service period of approximately 15 months	1. All specimens survived cyclic loading and no obvious failure could be observed 2. Within the control groups, Fp (cont) was significantly influenced by the type of implant–abutment connection (ANOVA, p < 0.001). The mean forces Fp (cont) for STR (456 N), FRI (368 N) and AST (430 N) were significantly lower than that of CAM (891 N) (p < 0.001). 3. Mechanical cycling considerably reduced the forces withstood by the implants. The resulting means of Fp (dyn) were 304 N (FRI), 347 N (NOB), 378 N (CAM), 394 N (AST), 397 N (STR) and 407 N (CAM) 4. Statistical analysis revealed that the type of implant–abutment connection has a significant influence on Fp (p < 0.001). Furthermore, dynamic loading proved to significantly influence Fp of BEG and CAM (p < 0.001). 5. The results of the present study suggest that conical implant– abutment connections may exhibit better continuity in yield forces over time.
				Bego	30 Ncm			
				Camlog	20 Ncm			
				Friadent	15 Ncm			
				Nobel Biocare	35Ncm			
				Straumann	35Ncm			

Table III / stress/ loading performance							
Bending moment/ maximal load resistance <i>continued</i>							
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result
Coppede et al., 2009	Internal cone, internal hex	Alvim II Plus implants with internal hex (IH) and with internal cone (IC) (Neodent Implants)	10	IH implants 10 Ncm, IC implants 20 Ncm (recommended by the manufacturer)	Resistance to bending moment/ maximal fatigue resistance	Maximal loading until failure, measuring maximal deformation force (MDF) and fracture force (FF)	IC: 90.58 6 6.72 kgf (MDF), no fracture , IH: 83.876 4.94 kgf (MDF), 79.8664.77 kgf (FF), significant difference for MDF
Norton et al., 2000	Internal cone, internal cone	OsseoSpeed (Astratech), standard ITI (ITI Straumann)	6	Astra 25 Ncm, ITI 35 Ncm (recommended by the manufacturer)	Resistance to bending moment/ maximal fatigue resistance	3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)	Astra: Mean Pb 4176 Nmm, mean Mb 5507 Nmm, significant higher bending moments at plastic deformation and failure than ITI: Mean Pb 2526 Nmm, mean Mb 3269 Nmm

Table III / stress/ loading performance							
Bending moment/ maximal load resistance <i>continued</i>							
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result
Norton et al., 2000	Internal cone, internal hex1 cone	OsseoSpeed (1-piece Uni-abutment St and 2-piece Profileabutment ST) (Astratech)	6	1-piece abutment 15 Ncm, 2-piece abutment 25 Ncm (recommended by the manufacturer)	Resistance to bending moment/ maximal fatigue resistance	3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)	Astra (1-piece): Mean Pb 4176 Nmm, mean Mb 5507 Nmm; Astra (2-piece): Mean Pb 4049 Nmm, mean Mb 6281 Nmm, no statistical significant differences
Norton et al., 1997	Internal cone, external hex	OsseoSpeed (Astratech), Branemark (Nobel Biocare)	6	Astra 8 Ncm, Branemark 20 Ncm (recommended by the manufacturer)	Resistance to bending moment/ maximal fatigue resistance	3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)	Astra: Mean Pb 1315 Nmm, mean Mb 2030 Nmm; Branemark: Mean Pb 645 Nmm , mean Mb 1262 Nmm , significant difference between systems

Table IV stress/ strain distribution								
Stress/ loading Performance								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Wang Kun, et al. 2016	Different Tapered abutments (taper angle: 6°;8°;10°)	N.a.(simulation)	30 prototype cylindrical titanium alloy 5.0 mm-diameter dental implants with different TIS-connection designs were divided into six group of 5 implants 3.5mm abutments group(3.5-6°, 3.5-8°, 3.5-10°); 4mm abutments group, (4-6°, 4-8°, and 4-10°)	N.A.(simulation)	To investigate the effects of abutment taper angles on the fracture strength of dental implants with TIS (taper integrated screwed-in) connection	3- Dimensional finite element analysis (FEA)was also used to analyse stress states at implant–abutment connection areas.	1. Finite element analysis Numerical simulations were carried out to evaluate the mechanical properties of the implants with different abutment taper angles with particular reference to the implant–abutment connection area where the fracture was expected to occur, 2. 3D models were generated using the SolidWorks 2008 software, A 200-N load, which was in the range of normal bite forces, was applied to the hemispherical dome of each implant with an inclination of 30° from the implant long axis	<ol style="list-style-type: none"> 1. the mechanical tests found an increasing trend of implant fracture forces as the taper angle enlarged 2. When the abutment diameter was 3.5 mm, the mean fracture forces for 8° and 10° taper groups were 1638.9 N ± 20.3 and 1577.1 N ± 103.2, respectively 3. increases of the abutment taper angle could significantly increase implant fracture resistance in most cases established in the study 4. Implants in group 3.5-8 had the highest mean maximum load level of 1638.9 N ± 20.3 5. Group 4-6 had the lowest mean maximum load value, which was significantly lower than that for the other five groups

Table IV stress/ strain distribution								
Stress/ loading Performance <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Yamanishi et al., 2012	External hex, internal cone, internal straight	N.a. (simulation)	N.a. (simulation)	N.a. (simulation)	Effect of implant abutment design on abutment micromovement , implant-abutment interface and periimplant stress distribution	N.A	Finite element analysis method (FEM), simulating an oblique load	External hex connection: Largest amount of abutment movement, higher labial bone stresses; Internal conical: Lowest abutment movement and low labial peri-coronal bone stresses
Saidin et al., 2012	Internal cone, trilobe, internal hex, internal octagon	N.a. (simulation)	N.a. (simulation)	N.a. (simulation)	Effect of implantabutment connection on micromotion and abutment stress distribution	N.A.	Finite element analysis method (FEM), simulating axial and oblique loads	Stress concentrates at vertices of non conical abutments ; conical abutments showed more uniformly distributed stresses; internal hex connection showed the greatest stresses, followed by internal conical, octagonal and the trilobed connection.

Table IV stress/ strain distribution								
Stress/ loading Performance <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Pellizzer et al., 2011	Internal hex, external hex, internal octagon 1 cone, internal cone, internal locking taper	Conexao Implant System (Conexao Systemas de Protese), ITI (Straumann), Bicon	5	According to the recommendation of the manufacturer	Strain/ stress distribution Around implants	N.a.	Photoelastic analysis under vertical and oblique loading	Axial load: Greatest stress concentration in the cervical and apical thirds. Oblique load: At the implant apex and in the cervical adjacent to the load direction. Internal octagon1+ cone presented the lowest stress concentrations, external hex exhibited the greatest stresses.
Nishioka et al., 2011	Internal cone, internal hex, external hex	Conexao Implant System (Conexao Systemas de Protese)	3	According to the recommendation of the manufacturer	Strain/ stress distribution around implants	Effect of implant abutment connection and implant fixture alignment	Strain gauge analysis	Statistically significant difference comparing the implant- abutment connections, Morse Taper and internal hexagon did not reduce strain around implants, no statistical significance in the placement configuration

Table IV stress/ strain distribution								
Stress/ loading Performance <i>continued</i>								
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Sec. objective	Materials and Methods	Result
Pessoa et al., 2010	Internal cone, internal hex, external hex	Neodent Implant System	N.A.	N.A	Stress/ strain in periimplant bone and influence on abutment and implant stability (before and after osseointegration)	Influence of connection type on bone-to-implant relative displacement and abutment microgap	Fenite element analysis method (FEM), simulating non-axial loading for immediate loaded and osseointegrated implants	Conical connection showed a significant higher abutment stability, the smallest microgap and the lowest stress in the abutment screw; marginal bone stresses were comparable for the simulation of immediate placed implants and lower for Morse Taper connection implants after osseointegration

Table IV stress/ strain distribution							
Stress/ loading Performance <i>continued</i>							
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result
Bernardes et al., 2009	Internal cone, internal hex, external hex, one-piece implant	Neodent Implant System	4	Not mentioned	Peri-implant stress fields generated from four different implant-abutment interfaces	Photoelastic strain analysis under different vertical centre and off-centre loading conditions	No significant difference under centered axial loading, smallest periimplant stress field for internal hexagonal connection under off-center loads; Internaltaper interfaces presented intermediate results
Quaresma et al., 2008	Internal cone, internal hex	Frialit-2, Ankylos (Dentsply Friadent)	N.a.	N.a.	Strain/ stress distribution in the prosthesis, abutment, implant and surrounding alveolar bone under different loading conditions	Finite element analysis method (FEM), simulating different vertical occlusal forces	Conical abutment showed lower stresses on alveolar bone and prosthesis and higher stresses on abutment. Internal hexagonal abutment showed higher bone stresses and lower abutment stresses

Table IV stress/ strain distribution							
Stress/ loading Performance <i>continued</i>							
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result
Akca et al., 2008	Internal cone, internal cone, internal cone, one-piece implant	synOcta, Monoblock ITI (ITI Straumann), Bicon Implants (Bicon), Osseo-Speed (AstraTech)	2 per system	Not mentioned	Force transmission in the peri-implant bone region of implants with different conical implant-abutment connections	Photoelastic and strain-gauge analysis under vertical and oblique forces	The internal cone implants showed similar interface force transfer characteristics that resemble a one-piece implant system
Lin et al., 2007	Internal cone, internal hex, internal cone	Frialit-2 (Dentsply Friadent), Bicon, standard ITI Straumann	N.a.	N.a.	Strain/ stress distribution around implants influenced by implant-abutment connection	Finite element analysis method (FEM), simulating different occlusal loads	Internal conical connection performed better as a force transmission mechanism than other systems, conical systems showed lower interface and marginal bone stresses than internal hexagonal connection system
Cehreli et al., 2004	Internal cone, internal cone, external hex	ITI Straumann, Astratech, Branemark (Nobel Biocare)	2 per system	Not mentioned	Force transfer characteristics of different implant abutment connections	Photoelastic and strain gauge analysis with vertical and oblique load application	Strains around Branemark implants were lower than around Astra and ITI implants particularly under vertical loads

Table IV stress/ strain distribution							
Stress/ loading Performance <i>continued</i>							
Author/ Year	Abutment connection	System	Specimens Number	Tightening torque	Primary objective	Materials and Methods	Result
Alkan et al., 2004	Internal cone, external hex, internal octagon	Branemark (Nobel Biocare), ITI solid, synOcta (ITI Straumann)	N.a	Simulated according to the manufacturers recommendations	Stress distribution of preloaded dental implant screws in different implantabutment joint systems under simulated occlusal forces	3-dimensional finite element analysis method (FEM), 3 simulating occlusal loads (horizontal, vertical, oblique)	In all systems maximum stress was examined between the shank and first thread of the abutment; stress increased in all systems under loading conditions
Merz et al., 2000	Internal cone, external hex	ITI and hypothetical butt joint ITI (ITI Straumann)	N.a.	Simulated with torque of 35 Ncm according to the recommendation of the manufacturer	Mechanics of two different implantabutment connections	Finite element analysis method (FEM), simulating vertical and different off-axis loads	Significant higher stress in the butt joint connection tightening the abutment to the implant, taper connection compensated high forces, butt joint showed more stress in the implant abutment connection

Table IV stress/ strain distribution							
Stress/ loading Performance <i>continued</i>							
Author/ Year	Abutment connection	System	Specime ns Number	Tightening torque	Primary objective	Materials and Methods	Result
Hansson et al., 2000	Internal cone, external flat top	N.a. (simulation)	N.a.	N.a.	Stress distribution around implants with conical and external flat implant abutment connections	Fenite element analysis method (FEM), simulated axial loading	Significant decrease in the peak bone implant interfacial shear stress in conical implant abutment connections , external flat top showed high marginal peri-implant stress peaks, conical system showed lower marginal stress peaks
Kitagawa et al., 2005	Internal cone, external hex	Ankylos (Dentsply Friadent), Branemark (Nobel Biocare)	N.a.	Ankylos 20 Ncm, Branemark 32 Ncm (recommended by the manufacturer)	Dynamic behavior (screw loosening) of different implant-abutment connections	Fenite element analysis method (FEM) comparing the movement of the taper-and external type-joint model	The external typejoint model showed rotation movement, the taper type-joint showed no movement

Marginal bone loss									
Author/ Year	Abutment connection	System	Animal model	Number of Animals	Implants number	Healing	Loading	Primary objective	Result
Weng et al., 2011a	Internal cone, external hex	Ankylos (Dentsply Friadent); Branemark (Nobel Biocare)	Mongrel dog.	6	4 groups a 6 implants (conical equicrestal and subcrestal, external hexagonal crestal and subcrestal)	non submerged	No	Radiographical evaluation of marginal bone loss	Marginal bone loss Conical: equicrestal (0.68±0.59 mm), subcrestal (0.76±0.49 mm) External: equicrestal (1.32±0.49 mm), subcrestal (1.88±0.81 mm)
Weng et al., 2011b	Internal cone, external hex	Ankylos (Dentsply Friadent); Branemark (Nobel Biocare)	Mongrel dog	8	4 groups a 8 implants (conical equicrestal and subcrestal, external hexagonal crestal and subcrestal)	submerged	No	Radiographical evaluation of marginal bone loss	Marginal bone loss Conical: equicrestal (0.48±0.66 mm), subcrestal (0.79±0.93 mm) External: equicrestal (0.69±0.43 mm), subcrestal (1.56±0.53 mm)
Berglundh et al., 2005	Internal cone, external hex	Astratech; Branemark (Nobel Biocare)	Beagle dog	6	24 implants per system	submerged	Yes	1 Radiographical marginal bone loss 2 Histological observation	Marginal bone loss: Astratech 0.09±0.16 mm, Branemark 0.77±0.42 mm
Abrahamson et al., 1998	Internal cone, external hex	Astratech; Branemark (Nobel Biocare)	Beagle dog	5	9 implants per system	submerged	No	1 Histological observation periimplant tissue, marginal bone loss 2 Soft tissue response Around implants to plaque formation	Marginal bone loss: Astratech 0.64±0.44 mm, Branemark 0.64±0.72 mm

Table VI/ Studies conducted in Humans											
Marginal bone loss											
Author / Year	Abutment connection	System	Study design	Follow up	Patients number	Implants number	Placed	Healing	Loading	Primary objective	Result
Pieri et al., 2011	Internal cone, internal hex	Samo Smiler Implants, Biospark	RCT.	12 months	40	40 (20 per group)	immediately	nonsubmerged	immediately	Clinical and radiographical outcome (marginal bone loss), implant success	Marginal bone loss: Conical 0.2±0.17 mm, internal hex 0.51±0.24 mm Implant success: Conical 94.7%, internal hex 100%
Bilhan et al., 2010	Internal cone, external hex	Astratech, Branemark (Nobel Biocare), ITI (Straumann)	CT	24 months	26	42 (Astra), 36 (Branemark), 29 (ITI)	delayed	submerged	delayed	Soft tissue, marginal bone loss, implant survival	Marginal bone loss: Astratech 0.66±0.1 mm, ITI 0.8±0.1 mm, Branemark 1.1±0.1 mm, Implant survival: all 100%
Crespi et al., 2009	Internal cone, external hex	Ankylos (Dentsply Friadent), Seven Sweden and Martina Implants	CT	24 months	45	34 (Branemark), 30 (Ankylos)	Immediately	nonsubmerged	Immediately	Marginal bone loss, implant survival	Marginal bone loss: Conical 0.73±0.52 mm, external hexagonal 0.78±0.45 mm Implant survival: both 100%

Table VI/ Studies conducted in Human											
Marginal bone loss <i>continued</i>											
Author / Year	Abutment connection	System	Study design	Follow up	Patients number	Implants number	Placed	Healing	Loading	Primary objective	Result
Kielbasa et al., 2009	Internal cone, external cone external trilobe	Nobel Active (NA) internal and external, Nobel Replace (NR, Nobel Biocare))	RCT multicenter study	12 month	177	117 (internal NA), 82 (external NA), 126 (NR)	delayed	nonsubmerged	immediately	Marginal bone loss and soft tissue behavior, implant survival rate	Implant survival: Internal NA 96.6%, external NA 96.3%, NR 97.6% Marginal bone loss: Internal NA 0.95±1.37 mm, external NA 0.64±0.97 mm, NR 0.63±1.18 mm

