The Stability of Implant-abutment Complex with Different Implant-abutment Connection Designs
—Review of Literature

Hsien-Ching Hong*,§, Yang-Ming Chang†,§, Yu-Hwa Pan†,§

*Department of General Dentistry, Chang-Gung Memorial Hospital, Taoyuan, Taiwan, R.O.C.
†Department of Oral Surgery, Chang-Gung Memorial Hospital, Taipei, Taiwan, R.O.C.
‡Department of General Dentistry, Chang-Gung Memorial Hospital, Taipei, Taiwan, R.O.C.
§Chang-Gung University, Taoyuan, Taiwan, R.O.C.

Abstract

The current review aimed to investigate the stability of implant abutment complex with different implant-abutment connection designs. Systematic review was conducted by online search of database PubMed, Medline (Ovid), Cochrane Library, Web of Science, and Google Scholar up to June 10, 2015. Besides, manual search was based on searching references in articles about related studies. There are 53 studies included in this review article. The included studies could be further categorized into 5 groups according to the test objectives (1) sealing ability, (2) fatigue loading test performance, (3) bending moment and maximum load resistance, (4) torque value of screw and preload, (5) stress and strain distribution over implant abutment interface. The conclusions are the following. First of all, internal cone connection seems to have superior sealing ability and minimal micro-gap because of the large surface area between implant fixture and abutment. Secondly, internal cone connection have better mechanical performance under fatigue loading and bending force. Thirdly, performance of torque values and preload in different connection design are still inconclusive. Fourthly, external hex connection tends to have stress concentration over coronal area whereas internal hex connection tends to spread force down to fixture tip. Internal cone connection showed more uniformly distributed stresses.

Key words: Implant abutment complex, Fatigue loading, Internal cone connection.

Introduction

Before the 1980’s, the implant treatment was originally used in rehabilitation of fully edentulous patient. Numerous studies and systematic reviews showed excellent results
Different Implant-abutment Connection Designs

With long term survival rates more than 80\%\textsuperscript{1,2}. With the advancement of implant body and corresponding abutment components designs, indication for implant rehabilitation have broaden to combine both fully and partially edentulous patients. Systematic review of the survival rates of fixed partial dentures supported by implants after an observation period of at least 5 years showed an estimated survival of implants in implant-supported FPDs of 95.4\% (95\% CI: 93.9–96.5\%) after 5 years and 92.8\% (95\% CI: 90–94.8\%) after 10 years\textsuperscript{3}. The survival rate of FPDs supported by implants was 95\% (95\% CI: 92.2–96.8\%) after 5 years and 86.7\% (95\% CI: 82.8–89.8\%) after 10 years of function.

Complications of implant treatment could be generally divided into 6 categories including surgical, implant loss, bone loss, peri-implant soft tissue, mechanical, and esthetic/phonetic\textsuperscript{3}. When it comes to mechanical complications, the cumulative incidence of connection-related complications (screw loosening or fracture) was 7.3\% which was second to 14\% for suprastructure-related complications (veneer and framework fracture) in systematic review conducted by Pjetursson, et al.\textsuperscript{4}. Several finite element method studies have pointed out that internal hex connection designs could distribute occlusal force deep within the implants compared to external hex connection designs\textsuperscript{9,10}. The internal connection designs also reduce the vertical height required for restorative component and potentially enhance the sealing ability through longer junction between the abutment and implant body. The 12 point internal hexagon (Osseotite Certain, 3i, Palm Beach, Florida, USA) which comprises of double hexagon provides the freedom to place implant in every 30 degree rotation, and other modification of internal connection such as 3 point internal tripod and internal octagon implant also distributed on the market.

**Connection designs**

The first implant–abutment connection design used by Branemark system was external hex which was developed for rehabilitation of completely edentulous ridge. Under such circumstances, implants were connected together with a metal bar as the artificial retainer of the complete denture\textsuperscript{5}. The Branemark external hex design comprises a male part of 0.7 mm external hex over implant platform and a corresponding female part over abutment. However, when the applications of implant dentistry broaden to single or multiple fixed partial dentures, antirotation, mechanical load resistance, and sealing ability of the implant–abutment complex have become an important issue\textsuperscript{6,7}. People modified the external hex design into other kinds of external connection designs such tapered hexagon, external octagon, and spline dental implant in order to promote its stability and reduce the possibility of screw loosening complication.

In the year 1986, Nickzick developed one of the first internal connection design with 1.7 mm–depth internal hex below the implant platform with 0.5 mm wide 45 degree bevel\textsuperscript{8}. Several finite element method studies have pointed out that internal hex connection designs could distribute occlusal force deep within the implants compared to external hex connection designs\textsuperscript{9,10}. The internal connection designs also reduce the vertical height required for restorative component and potentially enhance the sealing ability through longer junction between the abutment and implant body. The 12 point internal hexagon (Osseotite Certain, 3i, Palm Beach, Florida, USA) which comprises of double hexagon provides the freedom to place implant in every 30 degree rotation, and other modification of internal connection such as 3 point internal tripod and internal octagon implant also distributed on the market.

There is one kind of internal connection design that has distinct characteristic named conical connection or sometimes referred to as Morse taper implants or friction–fit implants. ITI Straumann implant system (Switzerland) is the first one utilized 8 degree morse taper as implant connection which composed of a 8 degree taper.
projection from implant abutment junction and fit into the corresponding recession in implant body\textsuperscript{11}. The friction fit and cold welding effect lead to the stability and sealing ability of implant abutment joint. There are also 11.5 degree Morse taper (Astra Tech) and 1.5 degree Morse taper (Bicon implant) available in the market.

In recent years, the implant–abutment complex design combines Morse taper with index (hexagon or octagon) was invented in order to combine the advantage of these two designs. There are still limited studies comparing its performance with other types of implant–abutment complex.

**Clinical significance**

According to the systematic review conducted by Goiato, et al. comparing clinical performances of implant supported fixed prostheses with different connection designs, it showed that internal connection performed better than external connection in terms of marginal bone loss and bacterial leakage\textsuperscript{12}. In the systematic review conducted by Gracis, et al. comparing internal and external connection designs showed that external connection design had higher incidence of technical complications\textsuperscript{13}. However, randomized control trials, cohort studies and case–control trials of long-term clinical outcomes have not well concluded the role of implant–abutment complex in both biological and mechanical aspects. Instable implant–abutment complex may lead to screw loosening or fracture which may constitute one of the most common mechanical complications in implant dentistry. Besides, instable implant–abutment complex will cause leakage at the implant–abutment interface and the corresponding bacterial contamination will lead to crestal bone loss or periimplantitis. This review article was aimed to evaluate the stability of different implant–abutment complex designs through in vitro studies which may provide clinicians information for choosing a proper connection design.

**Material and methods**

Systematic review was conducted by online search of database PubMed, Medline (Ovid), Cochrane Library, Web of Science, and Google Scholar up to June 10, 2015. Key words included “dental implant” or “implant” or “endosseous implant” and “implant–abutment complex” or “connection” or “internal hexagon” or “external hexagon” or “hexagonal” or “morse taper” or “conical implant abutment connection” or “conical” or “friction fit connection” or “butt joint connection” or “octogon” or “internal connection” or “external connection” and “abutment stability” or “screw stability” or “bending moment” or “torque” or “preload” or “load resistance” or “seal” or “sealing” or “stress” or “fatigue” or “stress and strain”. Besides, manual search was based on searching references in articles about related studies.

**Inclusion and exclusion criteria**

1. Comparative studies with at least 2 groups applying different connection designs or brands were included.
2. Studies with primary objective irrelevant of implant–abutment stability were excluded.

**Result**

There are 529 publications from the initial collected studies searched from electronic data
base (Figure 1). After reviewing of titles, key words, and abstracts, there are 356 articles were excluded, which left 173 articles for full-text screening. Eighty-two articles were excluded from full-text screening and there are 5 articles identified after manual search of references and full text. Ninety-six studies were analyzed in detailed evaluation and data extraction. After excluded by inclusion and exclusion criteria, a total of 53 studies were included in this review of literature.

These 53 included studies could be further categorized into 5 groups. (1) Fourteen studies were related to implant-abutment sealing ability. (2) Six studies were related to fatigue loading test performance. (3) Seven studies were related to bending moment and maximum load resistance. (4) Nine studies were related to torque value of screw and preload. (5) Seventeen studies were related to stress

Fig. 1. Flow chart of study result.
and strain distribution over implant abutment interface\textsuperscript{9, 10, 49-63}. All of the included studies were in vitro studies with several of them conducted by finite element analysis. The outcomes and characteristics of the studies were shown in Tables 1 to 5.

**Sealing ability**

There are 14 studies with regard to sealing ability of different implant–abutment complex designs in this review\textsuperscript{14-27}. Eight studies examined the bacterial leakage at the implant–abutment interface using bacterial species such as S.sanguinis, E.coli, Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, etc\textsuperscript{14, 17-20, 23, 24, 27}. Bacterial contamination could be found in the internal surfaces of all types of connections and internal conical connection seemed to have better sealing ability. Diversely, two studies conducted by Assenza, et al. and Ricomini, et al. showed that Bone System (cemented system) and external hex connection had better sealing ability than other test groups with 0% bacterial contamination\textsuperscript{17, 20}. One study conducted by Harder examined leakage with lipopolysaccharides\textsuperscript{21}. One study conducted by Nascimento examined leakage with human saliva and the result showed that conical connection had 1 out of 10 specimens with saliva contamination before mechanical loading which is better than internal hex (4 out of 10) and external hex (3 out of 10) connections\textsuperscript{16}. After mechanical loading the 3 connection designs showed similar results.

Two studies examined dye leakage with spectrophotometric analysis\textsuperscript{25, 26}. Gross et al. showed that leakage increased in all systems over time with no significant differences after 80 minutes and leakage decreased significantly as tightening torque increased to recommended values\textsuperscript{26}. Three studies checked the microgap of implant–abutment connections\textsuperscript{15, 22, 27}. Baixe, et al. compared internal cone, external flat and internal flat connections. The results showed that the mean microgap was larger for flat-to-flat interface systems compared to conical interface systems\textsuperscript{22}. Jansen et al. and Streckbein, et al. also showed similar conclusion that conical connection systems showed the smallest microgap and the mean microgap was less than 10 um in all tested systems\textsuperscript{15, 27}.

**Fatigue loading test performance**

There are 6 studies examined fatigue loading test performance\textsuperscript{28-33}. The loading force differed in different studies and the angles between loading force and long axis of the implants ranged from 0 to 90 degrees. Khraisat, et al. applied fatigue loading of 100N perpendicular to the long axis of the implant–abutment assemblies including internal cone and external hex designs. Internal cone design showed no failures after maximal cycles (1800000 cycles) while external hex design showed fractures between 1778023 to 1733526 cycles\textsuperscript{33}. Seetoh, et al. applied fatigue loading force of 21N in 45 degrees and Straumann zirconium abutments showed significant better load fatigue resistance than Ankylos and PrimaConnex implant abutment systems\textsuperscript{28}.

Perriard, et al. and Ribeiro, et al. examined F50 of different connection designs which means at which 50% of the sample failed\textsuperscript{29, 32}. Ribeiro et al. showed that F50 value of external hex connection is the highest followed by internal hex and internal cone\textsuperscript{29}. Perriard et al. compared traditional ITI standard abutment with SynOcta abutment and the result showed no difference in its mechanical resistance\textsuperscript{32}. Cehreli, et al.
Table 1. Studies related to sealing ability of the implant abutment complex.

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Connection</th>
<th>Method</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aloise, 2010</td>
<td>Bicon Implant System (Bicon, internal cone), Ankylos (Dentsply Friadent, internal cone)</td>
<td>Inoculation of S. sanguinis then connecting abutment and implant, incubation and proof of bacterial presence or absence</td>
<td>Bacterial leakage: Ankylos 20%, Bicon 20%</td>
</tr>
<tr>
<td>Assenza, 2012</td>
<td>Ankylos (Dentsply Friadent, internal cone), Replace Select (Nobel Biocare, internal trilobe), Bone System (cemented)</td>
<td>Bacterial inoculation of the implant and abutment connection then measuring bacterial leakage</td>
<td>Bacterial leakage: internal conical 1 out of 10, internal trilobed 6 out of 10, cemented 0 out of 10</td>
</tr>
<tr>
<td>Baixe, 2010</td>
<td>Ankylos (Dentsply Friadent, internal cone) → Ba, Osseo Speed (Astratech, internal cone) → Zr, Standard ITI (ITI Straumann, external flat) → Ca, Nobel Replace Tapered Groovy (Nobel Biocare, internal flat) → Nb</td>
<td>Longitudinal cutting and scanning with electron microscopy to check the microgap</td>
<td>The mean microgap was larger for flat-to-flat interface systems compared to conical interface systems, zirconia abutments showed smaller microgap than titanium abutments. Significant differences (P &lt; .001) were observed between mean (± SD) microgap measurements of the four tested systems: Ba = 0.38 ± 0.28 μm; Zd = 0.55 ± 0.23 μm; Nb = 1.83 ± 3.21 μm; Ca = 0.90 ± 0.59 μm. The mean microgap of the first 20 μm of the outer region (1.66 μm) was significantly (P &lt; .001) larger than the mean microgap (0.56 μm) of the inner region (30 to 100 μm).</td>
</tr>
<tr>
<td>Coelho, 2008</td>
<td>Standard SLA implant (ITI, Straumann, internal cone), Replace Select (Nobel Biocare, internal trilobe), Intralock short collar implant (Intra-lock Int., internal hex)</td>
<td>Contamination of implant interface, and connecting the implant to the abutment and measuring dye leakage over time with spectrophotometric analysis</td>
<td>Total release after 144 h: ITI 55%, Intra-lock 22% and Replace Select 100%</td>
</tr>
<tr>
<td>do Nascimento, 2012</td>
<td>SIN, Sistema de Implante Nacional (internal cone, internal hex, external hex)</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Author, Year</td>
<td>Materials and Methods</td>
<td>Findings</td>
<td>Conclusion</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Gross, 1999</td>
<td>ITI (Straumann, internal cone), 3i (external hex), Cera One and Steri-Oss (Nobel Biocare, external hex), Spline (Sulzer Calcitek, spline)</td>
<td>Contamination of implant interface, connection of implant fixture with abutment and measuring dye leakage over time with spectrophotometric analysis</td>
<td>Leakage increased in all systems over time with no significant differences after 80 minutes, leakage decreased significantly as tightening torque increased to recommended values</td>
</tr>
<tr>
<td>Harder, 2010</td>
<td>Osseo Speed (Astra Tech, internal cone), Ankylos (Dentsply Friadent, internal cone)</td>
<td>Inoculation of implant with LPS, connection to abutment and incubation, endotoxin detection and measuring concentration over time (168h)</td>
<td>Endotoxin detection in both groups after 5 minutes. Significant less endotoxin concentration (mean) for Osseo Speed units over the whole examination period</td>
</tr>
<tr>
<td>Jansen, 1997</td>
<td>Osseo Speed (Astratech, internal cone), Ankylos (internal cone), Friali-t-2, IMZ (Dentsply Friadent, flat with/without silicone washer), Bonefit conical (internal cone) and syn Octa (ITI Straumann, internal cone), Branemark (Nobel Biocare, external flat), Semados (Bego Semados, external flat),</td>
<td>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</td>
<td>All systems showed bacterial leakage of the implant abutment interface after 5 days, the micro gap was less than 10 um in all systems, conical connection systems showed the smallest micro gap</td>
</tr>
<tr>
<td>Koutouzis, 2011</td>
<td>Ankylos (Dentsply Friadent, internal cone), Bone level (ITI Straumann, internal cone)</td>
<td>Implant abutment connection, loading in E.coli medium, disconnection measuring loosening torque, incubation and measuring CFUs</td>
<td>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)</td>
</tr>
<tr>
<td>Ricomini, 2010</td>
<td>Internal cone 1 (one piece), internal cone 2 (two pieces), external hex, locking taper</td>
<td>Connection, thermal cycling and mechanical fatigue testing, sterilization to bacterial medium, detorque measurements and SEM</td>
<td>Bacterial leakage after loading: Morse Taper 1 (67%), Morse Taper 2 (50%), external hexagonal (0%), locking taper (60%) Preload loss aftercycling: Morse Taper 1 (12.5%),</td>
</tr>
<tr>
<td>Streckbein, 2012</td>
<td>Branemark (external hex), Camlog (internal flat), Xive (internal hex), Bego (internal cone), Straumann (internal cone), Astra (internal cone), Ankylos (internal cone)</td>
<td>30N, 0N, 40N, 0N for strain measurement; 120N, 30 degree for microgap measurement</td>
<td>Conical implant–abutment connections efficiently avoided micro–gaps but had a negative effect on peri-implant bone strain. micro–gap: Branemark 0.5 um, Camlog: 3.4 um, Xive 1.8 um, Bego 0 um, Straumann 0 um, Astra 0 um, Ankylos 0 um</td>
</tr>
</tbody>
</table>
Different Implant–abutment Connection Designs

Teixeira, 2011
Titamax CM (internal cone), Titamax II Plus (Neodent, internal hex)
Bacterial contamination before and after implant–abutment connection, incubation and colony growth calculation
Result of bacterial leakage into inner part of the implants: Conical 70% and internal hex 100% leakage.
Result of bacterial leakage from the inner part of the implants: Conical 77.7% and internal hex 100% leakage.

Tesmer, 2009
Ankylos and manipulated Ankylos (Dentsply Friadent, internal cone), Nobel Replace Select (Nobel Biocare, tri-channel internal connection)
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; Aa24.5, Pg 12), manipulated Ankylos: (Aa 10/10, Pg 10/10, CFUs; Aa 81, Pg 55)

Tripodi, 2012
Universal II HI and CM, (Implacil De Bortoli) (internal cone and internal hex)
Bacterial inoculation of the implant and abutment connection and detecting bacterial leakage
PS (Pseudomonas aeruginosa inoculation): 2 out of 5 in the conical group and 2 out of 5 in the internal hex group
AA (Aggregatibacter actinomycetemcomitans): 0 out of five in the conical and 3 out of 5 in the internal hex group

Table 2. Studies related to fatigue loading test performance of the implant abutment complex

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Connection</th>
<th>Method</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cehreli, 2004</td>
<td>ITI Solid (internal cone) and Syn–Octa implants (ITI Straumann, internal cone+octagon)</td>
<td>Fatigue loading (Cyclic dynamic axial and lateral peak loads of 75 ± 5 N were applied on the implants for a duty of 500,000 cycles at 0.5 Hz, and at an angle of 20 degree). Periotest value (PTVs) measurements after every 100,000 cycles). Removal torque value (RTV) measurement after termination</td>
<td>All abutments and implants were clinically immobile and without any signs of mechanical failure. The final PTVs for both abutments were similar and the difference between groups was insignificant (P &gt; 0.05). The RTVs of solid abutments were significantly higher than synOctas abutments (P &lt; 0.05) RTVs of synOctas and solid abutments were 22.42 (0.56) Ncm and 32.31 (0.82) Ncm, respectively</td>
</tr>
<tr>
<td>Study</td>
<td>Implant System</td>
<td>Fatigue Loading</td>
<td>Conclusion</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Khraisat, 2002</td>
<td>Branemark (Nobel Biocare, external hex), ITI Solid screw (ITI Straumann, internal cone)</td>
<td>Fatigue loading (A cyclic load of 100 N was applied perpendicular to the long axis of the assemblies at a rate of 75 cycles/min until failure of the implant abutment specimens or maximal cycles (1,800,000 cycles), fracture surface analysis with SEM</td>
<td>ITI solid screw: no failures, Branemark: fracture between 1,778,023 and 1,733,526 cycles (significant difference); fractures occurred between the threaded and unthreaded parts of the abutments</td>
</tr>
<tr>
<td>Perriard, 2002</td>
<td>ITI Standard (S, internal cone) and synOcta (O, internal cone + octagon) implants (ITI Straumann) + Solid (S) and synOcta (O) abutments (ITI Straumann)</td>
<td>Implant abutment connection and fatigue loading (step procedure, and calculating F50 (loading with 50% survived), FEM detecting stress peaks in implant-abutment connection</td>
<td>S-O connection more resistant to force application; S-O combination superior to O-O and S-S; S-S and O-O comparable; in cases of fracture there is no preferential location detectable in all three groups; stresses in the implant-abutment interface: O-O more stresses than S-O and S-S</td>
</tr>
<tr>
<td>Quek, 2008</td>
<td>Branemark CeraOne (Nobel Biocare, external hex), 3i Osseotite-STA (3i, Biomet, external hex), Replace Select- Easy (Nobel Biocare, cam tube), Lifecore Starge-1-COC (LC Lifecore Biomedical, internal cone)</td>
<td>Fatigue loading (rotational load fatigue, sinusoidally applied 35 Ncm bending moment at implant abutment interface, 14 Hz) until failure or maximal cycles (5000000 cycles). Examination of the fracture region and surface with SEM</td>
<td>No statistical significant differences in the number of cycles to failure between the four systems when recommended torque values were used; failure location is system specific and always occurs at the weakest point of the implant abutment connection</td>
</tr>
<tr>
<td>Ribeiro, 2011</td>
<td>Conexao Implant Systems (Conexao Sistemas de Protese) Internal cone, internal hex, external hex</td>
<td>Fatigue loading and calculating of the F50 value (at which 50% of the samples failed and 50% ran out), stereomicroscopy and SEM analysis of fracture region</td>
<td>External hexagonal: F50, 5356.78 N internal conical: F50, 4462.49 N internal hexagonal: F50, 4563.40 N In 24 out of 30 cases fracture region was observed in the threaded part of the abutment.</td>
</tr>
<tr>
<td>Seetoh, 2011</td>
<td>Ankylos (Dentsply Friadent, internal cone), Lifecore Prima Connex (Keystone Dental, internal cone+hex), Bone Level (ITI Straumann, internal cone + 4 groove)</td>
<td>Fatigue loading (21N 45 degree which equals to 35 Ncm at implant abutment interface) until failure of the implant abutment specimens or maximal cycles (10 Hz, 5000000 cycles). SEM analysis of fracture region</td>
<td>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.</td>
</tr>
</tbody>
</table>
Table 3. Studies related to bending moment and maximum load resistance of the implant abutment complex

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Connection</th>
<th>Method</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coppede, 2009</td>
<td>Alvim II Plus implants with internal hex (IH) and with internal cone (IC) (Neodent Implants)</td>
<td>Maximal loading until failure, measuring maximal deformation force (MDF) and fracture force (FF)</td>
<td>IC: $90.58 \pm 6.72$ kgf (MDF), no fracture IH: $83.87 \pm 4.94$ kgf (MDF), $79.86 \pm 4.77$ kgf (FF) significant difference for MDF</td>
</tr>
<tr>
<td>Michalakis, 2014</td>
<td>3i (Palm Beach Gardens, Fla, external hex), MIS Implant Technologies Ltd, Shlomi, Israel (internal hex)</td>
<td>30 mm/min on cingulum till 0.5 mm, 1 mm, 2 mm, 2.5 mm displacement</td>
<td>The external connection implant system required significantly greater loads ($P &lt; .001$) than the internal connection implant system for displacements of 1, 2, and 2.5 mm to be achieved.</td>
</tr>
<tr>
<td>Norton, 1997</td>
<td>OsseSpeed (Astratech, internal cone), Branemark (Nobel Biocare, external hex)</td>
<td>3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)</td>
<td>Astra: Mean Pb 1315 Nmm, mean Mb 2030 Nmm Branemark: Mean Pb 645 Nmm, mean Mb 1262 Nmm</td>
</tr>
<tr>
<td>Norton, 2000</td>
<td>OsseSpeed (1-piece Uni-abutment St (internal cone) and 2-piece Profileabutment ST (internal cone+hex)) (Astratech)</td>
<td>3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)</td>
<td>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</td>
</tr>
<tr>
<td>Norton, 2000a</td>
<td>OsseSpeed (Astratech, internal cone), standard ITI (ITI Straumann, internal cone)</td>
<td>3 point bending test until failure or maximum load, measuring plastic bending moment (Pb) and maximal bending moment (Mb)</td>
<td>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</td>
</tr>
<tr>
<td>Pedroza, 2007</td>
<td>Screw–Vent system (internal hex), Spline system (external connection), Unipost system (internal connection)</td>
<td>Implant axis 30-degree to y axis of universal testing machine, loaded with compression at a rate of 0.02 in/min until failure</td>
<td>The mean compressive strength for the Unipost system was 392.5 psi (SD ± 40.9), for the Spline system 342.8 psi (SD ± 25.8), and for the Screw–Vent system 269.1 psi (SD ± 30.7)</td>
</tr>
<tr>
<td>Truninger, 2012</td>
<td>Straumann bone level (1 piece internal, zircornia, internal cone)→BL, Nobel Biocare (2 piece internal, zircornia)→RS, Branemark (external, zircornia)→B, Straumann standard plus(2 piece internal, zircornia)→SP, Straumann bone level (1 piece, titanium)→T as control</td>
<td>49 N, 1200000 cycle, 1.67 Hz, 30 degree to implant long axis, followed by 30 degree 1 mm/min load to failure, 5–50°C 120 sec (simultaneous with chewing cycle)</td>
<td>The mean bending moments of the abutments were 714.1 ± 184.9 Ncm (T), 331.7 ± 57.8 Ncm (BL), 429.7 ± 62.8 Ncm (RS), 285.8 ± 64.4 Ncm (B) and 379.9 ± 59.1 Ncm (SP). The bending moments of control group T were significantly higher than those of all other groups. The values of group RS were significantly higher than those of group B but within the value range of groups SP and BL</td>
</tr>
</tbody>
</table>
Table 4. Studies related to torque value of screw and preload of the implant abutment complex

<table>
<thead>
<tr>
<th>Torque value of screw and preload</th>
<th>Method</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author/Year</strong></td>
<td><strong>Connection</strong></td>
<td><strong>Method</strong></td>
</tr>
<tr>
<td>Ding, 2003</td>
<td>Standard and syn-Octa ITI (ITI Straumann), internal cone, internal cone + octagon</td>
<td>Measuring repeated in/out torque values and maximal bending moment (30-degree off-axis angle), SEM</td>
</tr>
<tr>
<td>Feitosa, 2013</td>
<td>Neodent (external hex, internal hex, internal cone)</td>
<td>axil force 400N, 8 Hz,1000000 cycles. The application and registration of the screw torque (T0) and detorque (T1) values of the intermediatem were performed before and after the test</td>
</tr>
<tr>
<td>Norton, 1999</td>
<td>Astratech (diameters 3.5 and 5.0, internal cone), standard ITI (ITI Straumann, internal cone)</td>
<td>Measuring different tightening and the resulting removal torques in wet and dry environments</td>
</tr>
<tr>
<td>Park, 2010</td>
<td>Osstem Implant Systems (US II, SS II, GS II) Internal cone, internal cone + external colar, external hex</td>
<td>Measuring compression force and tightening and removal torque before and after loading (1000000 cycles)</td>
</tr>
<tr>
<td>Piermatti, 2006</td>
<td>OsseoSpeed (Astratech, internal cone), Bio-Lok (Bio-Lok, external hex), Branemark (Nobel Biocare, external hex), Screw-vent (Zimmer Dental, internal cone + hex)</td>
<td>Off axis loading (200 N) of the specimens and recording removal torque every 250.000 cycles up to 1000000 cycles</td>
</tr>
<tr>
<td>Ricciardi, 2009</td>
<td>Alvim CM implants and Universal abutment CM one and two-piece (Neodent), internal cone</td>
<td>Measuring removal torque after repeated insertion/removal and after loading (1,325 cycles) (mechanical loading device, developed by the Department of Dental Materials and Prostheses of the School of Dentistry of Ribeirão Preto, University of São Paulo, which simulates masticatory movements), SEM groups 1 and 3 received solid abutments, and groups 2 and 4 received two-piece abutments. In groups 1 and 2, abutments were simply installed and uninstalled; torque-in and torque-out values were measured. In groups 3 and 4, abutments were installed, mechanically loaded and uninstalled; torque-in and torque-out values were measured.(4a: torque-out value necessary to loosen the fixation screw; 4b: torque-out value necessary to remove the abutment from the implant) Torque loss was higher in groups 4a and 2 (over 30% loss), followed by group 1 (10.5% loss), group 3 (5.4% loss) and group 4b (39% torque gain).</td>
</tr>
<tr>
<td>Shin, 2014</td>
<td>US II implant had an external-hex butt joint connection, SS II implant had an internal conical connection with 8 degree Morse Taper with 2.8 mm collar neck for one-stage purpose, GS II implant had an internal conical connection with an 11 degree Morse Taper sine-type 150N~10N, 10Hz, 5 mm from center of long axis 10000 cycles and re-torque and 100000 cycles, measure removal torque loss The results of this study showed that the external butt joint was more advantageous than the internal cone in terms of the postload removal torque loss. For the difference in the implant diameter, a wide diameter was more advantageous in terms of the torque loss rate. The postload removal torque value was high in the following order with regard to magnitude: two-stage internal cone, one-stage internal cone, and external butt joint systems. In the regular-diameter group, the external butt joint and one-stage internal cone systems showed lower postload removal torque loss rates than the two-stage internal cone system. In the wide-diameter group, the external butt joint system showed a lower loss rate than the one-stage internal cone and two-stage internal cone systems. In the two-stage internal cone system, the wide diameter group showed a significantly lower loss rate than the regular-diameter group (P&lt;.05)</td>
<td></td>
</tr>
</tbody>
</table>
Weiss, 2000  |  Standard ITI (ITI Straumann, internal cone), SpectraClone (Alpha Bio, internal cone), Spline, Integral (flat rim) and Omnitek (internal octagon) (Calcitek),  |  200 repeated consecutive closing/opening cycles and measuring the torque values  |  Significant higher maintaining torque values in either conical frictional elements or interlocking lines, removal torque declined for all systems progressively up to 200 c/o cycles  

Villarinho, 2015  |  Internal cone, internal cone with hex (Munha´o Universal CM Exact, Neodent)  |  The preload values for each abutment screw after a tightening torque were registered by strain gauges. Prosthetic crowns were placed on each abutment and subjected to mechanical cycling. Detorque forces were applied to each abutment and compared with the initial torque values.  |  The nonindexed group presented higher initial preload (6.05 N ± 0.95 N) compared with the indexed group (4.88 N ± 0.92 N; P < .05). After cycling, the nonindexed group exhibited less reduction of preload (13.84% ± 6.43%) compared with the indexed group (52.65% ± 14.81%; P < .01). Indexed tapered abutments for single-crown restorations might represent greater biomechanical risk under function.  

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Connection</th>
<th>Method</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akca, 2008</td>
<td>synOcta, Monoblock ITI (ITI Straumann, internal cone), Bicon Implants (Bicon, internal cone), Osseo-</td>
<td>Photoelastic and strain-gauge analysis under vertical and oblique forces (vertical or 20 degree, 75N)</td>
<td>The internal cone implants showed similar interface force transfer characteristics that resemble a one-piece implant system.</td>
</tr>
<tr>
<td>Alkan, 2004</td>
<td>(1) Branemark external hexagonal screw-retained abutment, (2) ITI 8-degree Morse tapered cemented abutment, and (3) ITI 8-degree Morse tapered plus internal octagonal screw-retained abutment.</td>
<td>3-dimensional finite element analysis method (FEM), 3 simulated occlusal loads (10 N; horizontal, 35 N; vertical, 70 N; oblique)</td>
<td>In all systems maximum stress was examined between the shank and first thread of the abutment screws; when vertical and oblique static loads were applied, stresses decreased in the external hexagonal and internal octagonal plus 8-degree Morse tapered abutment and prosthetic screws with the exception of the prosthetic screw of ITI abutment after 70-N oblique loading. Stresses increased in the ITI 8-degree Morse tapered cemented abutment after both vertical and oblique loads.</td>
</tr>
<tr>
<td>Author, Year</td>
<td>Connection Design</td>
<td>Method of Measurement</td>
<td>Results</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Balik, 2012</td>
<td>external hex, internal hex, conical + internal hex, tube in tube, Morse taper</td>
<td>100N vertical and 50N horizontal force (FEM), measure stress in abutment and screw</td>
<td>external hex showed highest strain value while conical connection systems showed lowest value. Conical + internal hexagonal and screw-in implant abutment connection designs provide more biomechanically suitable prosthetic options than other systems.</td>
</tr>
<tr>
<td>Bernandes, 2009</td>
<td>Neodent Implant System, Internal cone, internal hex, external hex, one-piece implant</td>
<td>Photoelastic strain analysis under different vertical center and offcenter loading conditions</td>
<td>No significant difference under centered axial loading, smallest peri-implant stress field for internal hexagonal connection under off-center loads; Internal taper interfaces presented intermediate results, and one-piece and external-hex implants resulted in high stress levels.</td>
</tr>
<tr>
<td>Cehreli, 2004</td>
<td>ITI Straumann (internal cone), Astratech (internal cone), Branemark (Nobel Biocare, external hex)</td>
<td>Photoelastic and strain gauge analysis with vertical and oblique load application</td>
<td>Strains around Branemark implants were lower than around Astra and ITI implants particularly under vertical loads.</td>
</tr>
<tr>
<td>Covani, 2013</td>
<td>premium implant (modified internal hex, internal hex, standard connection without hex, external connection)</td>
<td>100N applied to the occlusal surface for 0.2 sec and stopped for 0.6 sec, 450 N 30 degree for fatigue test (FEM + in vitro), measure transient response of the dental implant to load</td>
<td>The results of FEM analysis indicated that the implant modified configuration is more efficient in loading support when compared with the others. Internal hex connection with the modification of the manufacturer's original is much more resistant to loosening and/or distortion than the traditional hex.</td>
</tr>
<tr>
<td>Hansson, 2000</td>
<td>Internal cone, external flat top</td>
<td>Fenite element analysis method (FEM), simulated axial loading</td>
<td>Significant decrease in the peak boneimplant interfacial shear stress in conical implant abutment connections, external flat top showed high marginalperi-implant stress peaks, conical system showed lower marginal stress peaks.</td>
</tr>
<tr>
<td>Kitagawa, 2005</td>
<td>Ankylos (Dentsply Friadent, internal cone), Branemark (Nobel Biocare, external hex)</td>
<td>Fenite element analysis method (FEM) comparing the movement of the taper<del>and external type</del> joint model</td>
<td>The external type joint model showed rotation movement, the taper type~joint showed no movement.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Implant System/Method</td>
<td>Description</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>Lin, 2007</td>
<td>Frialit-2 (Dentsply Friadent), Bicon, standard ITI Straumann (Internal cone, internal hex, internal cone)</td>
<td>Fenite element analysis method (FEM), simulating different occlusal loads</td>
<td>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.</td>
</tr>
<tr>
<td>Maeda, 2006</td>
<td>Nobel Biocare (external hex, internal hex)</td>
<td>static 30 N vertical and horizontal to abutment, measure strain over abutment, cervical and fixture tip areas of the bone analogue (strain gauge)</td>
<td>Internal–hex showed widely spread force distribution down to the fixture tip compared with external hex ones. Vertical load: no significant difference between 2 group.</td>
</tr>
<tr>
<td>Merz, 2000</td>
<td>ITI and hypothetical butt joint ITI (ITI Straumann)</td>
<td>Fenite element analysis method (FEM), simulating vertical and different off-axis loads (380N, 0, 15, 30 degree, 35 N–cm screw torque)</td>
<td>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.</td>
</tr>
<tr>
<td>Nishioka, 2011</td>
<td>Conexao Implant System (Conexao Systemas de Protese) (Internal cone, internal hex, external hex)</td>
<td>Strain gauge analysis</td>
<td>There was no evidence that there was any advantage to the offset placement of implants as compared with straightline placements. Morse Taper and internal hexagon did not reduce strain around implants.</td>
</tr>
<tr>
<td>Pellizzer, 2014</td>
<td>model 1, internal hexagon implant (4.0x10 mm; Conect AR, Conexa’s, São Paulo, Brazil); model 2, Morse taper/internal octagon implant (4.1 x 10 mm; Standard, Straumann ITI, Andover, Mass); model 3, Morse taper implant (4.0 x 10 mm; AR Morse, Conexa’s); model 4, locking taper implant (4.0 x 11 mm; Bicon, Boston, Mass); model 5, external hexagon implant (4.0 x 10 mm; Master Screw, Conexa’s)</td>
<td>photoelastic resin with an implant and a healing abutment. Axial and oblique load (45 degree) of 150 N were applied by a universal testing machine (EMIC-DL 3000), and a circular polariscope was used to visualize the stress.</td>
<td>For the axial load, the greatest stress concentration was exhibited in the cervical and apical thirds. However, the highest number of isochromatic fringes was observed in the implant apex and in the cervical adjacent to the load direction in all models for the oblique load. Model 2 (Morse taper, internal octagon, Straumann ITI) presented the lowest stress concentration, while model 5 (external hexagon, Master Screw, Conexa’s) exhibited the greatest stress. It was concluded that Morse taper implants presented a more favorable stress distribution among the test groups. The external hexagon implant showed the highest stress concentration. Oblique load generated the highest stress in all models analyzed.</td>
</tr>
</tbody>
</table>
Different Implant-abutment Connection Designs

<table>
<thead>
<tr>
<th>Reference</th>
<th>System</th>
<th>Methodology</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pessoa, 2010</td>
<td>Neodent Implant System (Internal cone, internal hex, external hex)</td>
<td>Fenite element analysis method (FEM), simulating non-axial loading for immediate loaded and osseointegrated implants</td>
<td>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</td>
</tr>
<tr>
<td>Quaresma, 2008</td>
<td>Frialit-2 (internal hex), Ankylos (Dentsply Friadent, internal cone)</td>
<td>Fenite element analysis method (FEM), simulating different vertical occlusal forces (Simulated, 50–N vertical loads were applied to the buccal and lingual cusp ridges of the buccal cusp of the implant prostheses) for a total loading of 100 N</td>
<td>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</td>
</tr>
<tr>
<td>Saidin, 2012</td>
<td>Internal cone, trilobe, internal hex, internal octagon</td>
<td>Fenite element analysis method (FEM), simulating axial and oblique loads (For axial loading, a force of 230 N was applied to the second premolar, 300 N to the crown and 350 N to the second molar. A buccolingual load of 100 N was also applied and was 30 degree from the</td>
<td></td>
</tr>
<tr>
<td>Yamanishi, 2012</td>
<td>External hex, internal cone, internal straight</td>
<td>Fenite element analysis method (FEM), simulating an oblique load</td>
<td>Stress concentrates at vertices of nonconical abutments; conical abutments showed more uniformly distributed stresses. Internal hex connection showed the greatest stresses. The internal conical abutment produced the highest magnitude of micromotion, whereas the trilobe connection showed the lowest magnitude of micromotion due to its polygonal profile.</td>
</tr>
</tbody>
</table>

Also compared ITI standard abutment with SynOcta abutment. Periotest value was checked after functional loading. The result showed no difference between solid abutments and SynOcta abutments. Quek, et al. applied rotational load fatigue and the result showed that no statistical significant differences in the number of cycles to failure among external hex connection, camtube connection, and internal conical connection when recommended torque values were used.  

**Bending moment and maximum load resistance**

There are 7 studies regarding bending moment and maximum load resistance of implant-abutment complex in this review. Michalakis, et al. compared external hex connection with internal hex connection using bending force. The results showed that the external hex implant.
connection system required significantly greater loads \((p < .001)\) than the internal connection implant system for displacements of 1, 2, and 2.5 mm to be achieved\(^{32}\). On the contrary, according to studies conducted by Coppede and Norton, internal cone connection have better performance on bending moment and maximum load resistance comparing to internal hex or external hex connection\(^{36, 38, 40}\).

Norton et al. also compared internal cone connection with internal cone connection combined with hex as modification and the results showed that internal cone with hex as modification with higher maximal bending moment but without significant difference\(^{36}\). Pedroza, et al. applied implants axis 30-degree to y axis of universal testing machine and loaded with compression at a rate of 0.02 in/min until failure. The result showed the mean compressive strength for the Unipost system was 392.5 psi, for the Spline system 342.8 psi, and for the Screw-Vent system 269.1 psi\(^{37}\). Truninger, et al. compared multiple implant systems including zirconia one-piece internal implant–abutment connection (BL; Straumann Bone level), zirconia two-piece internal implant–abutment connection (RS; Nobel Biocare Replace Select), zirconia external implant–abutment connection (B; Branemark MK III), zirconia two piece internal implant–abutment connection (SP; Straumann Standard Plus). Titanium abutments with one-piece internal implant–abutment connection (T; Straumann Bone level) served as control group. The mean bending moments of the abutments were 714.1 ± 184.9 Ncm (T), 331.7 ± 57.8 Ncm (BL), 429.7 ± 62.8 Ncm (RS), 285.8 ± 64.4 Ncm (B) and 379.9 ± 59.1 Ncm (SP)\(^{35}\).

There are 9 studies regarding torque value of screw and preload of implant–abutment complex in this review\(^{11, 41-48}\). Most of the studies compared removal torque before and after mechanical loadings. Piermatti, et al. compared different implant systems under off axis loadings. The result showed the Bio–Lok samples lost an average of 10% of the original torque values. Astra Tech group lost almost all of the torque and loosened. Zimmer and Nobel Biocare samples lost an average of 50% of the torque \((P \leq 0.05)\)\(^{46}\). Feitosa, et al., Park, et al., and Weiss, et al compared torque values before and after loadings. Morse taper connection showed better stability among those studies\(^{43, 44, 47}\). On the contrary, Shin et al. measured removal torque loss after loadings and the result showed that the external butt joint was more advantageous than the internal cone in terms of the postload removal torque loss\(^{42}\).

Villarinho, et al. compared internal cone system with or without index. After cycling, the non–indexed group exhibited less reduction of preload \((13.84\% \pm 6.43\%)\) compared with the indexed group \((52.65\% \pm 14.81\%; P < .01)\)\(^{41}\). Norton et al. showed cold welding did not occur between 20 and 40 Ncm and surface area of interface seems to influence torque loss\(^{48}\). Ricciardi, et al. showed that torque–out value necessary to remove the 2–piece internal cone abutment from the implant after loading had 39% gain compared with preload torque value. One may say that this result could be attributed to the cold welding effect of the internal conical connection\(^{45}\). Ding et al. compared ITI standard abutment with SynOcta abutment. The result showed that initial removal torque of solid abutments combined with standard and Syn–Octa implants were significantly higher than the initial removal torque of the SynOcta implant combined.

**Torque value of screw and preload**
with SynOcta abutment.

**Stress and strain distribution over implant abutment interface**

There are 17 studies regarding stress and strain distribution over implant abutment interface in this review. Eleven studies applied finite element analysis method simulating functional load and stress distribution. Most of the studies applied FEM concluded that conical connection showed lower stress over bone-implant interface compared with other connection designs. Alkan, et al. showed that maximum stress was examined between the shank and first thread of the abutment screws in different systems. Yamanishi, et al. observed that external hex connection had larger abutment movement and bone stress compared with internal cone connection. Pessoa et al. showed that conical connection showed a significant higher abutment stability, the smallest microgap and the lowest stress in the abutment screw. Balik, et al., Hasson, et al., Lin, et al., and Quaresma, et al. also showed that internal conical connection had lower stress and strain value under loadings.

There are 6 studies use photoelastic and strain-gauge analysis for stress observation. Akca, et al. compared different conical connection systems and showed that the internal cone implants showed similar interface force transfer characteristics that resemble a one-piece implant system. Pellizzer, et al. observed that Morse taper implants presented a more favorable stress distribution among the test groups. The external hexagon implant showed the highest stress concentration. Bernardes, et al. showed that smallest peri-implant stress field was observed for internal hexagonal connection under off-center loads. Internal taper interfaces presented intermediate results, and one-piece and external-hex implants resulted in high stress levels. Diversely, Cehreli, et al. showed that strains around Branemark implants(external hex connection) were lower than around Astra and ITI implants particularly under vertical loads. Maeda et al. compared external hex connection with internal hex connection and the results showed that internal-hex showed widely spread force distribution down to the fixture tip compared with external hex ones.

**Discussion**

This review focused on laboratory studies because in vitro studies could have better control of variances than clinical studies. Besides, it is hard to observed mechanical properties such as stress and strain values, torque loss, and bending force of implant–abutment complex through clinical studies. However, relevance of in vitro studies are limited by the precision of simulating the oral environment. Lack of standardized protocols makes it hard to compare between the in vitro studies.

Crestal bone loss is an important factor determines the success of the implants. Bone responds to both hormonal and biomechanical regulation. Stress concentration over crestal bone may lead to crestal bond loss. Studies in this review showed that stress distribution over implant–bone interface could be affected by connection designs. Studies applied FEM, photoelastic and strain-gauge analysis showed that conical connection designs have well distributed stress compared with other designs. However, clinical studies showed implant–abutment connection appears to have
no significant impact on short-term peri-implant crestal bond change\textsuperscript{64}. So stress distribution affected by connection designs may not be a key factor for peri-implant bone loss since other factors such as plaque induce periimplantitis or occlusal overloading may also play a role. In all systems, maximum stress was examined between the shank and first thread of the abutment screws\textsuperscript{61}. This may explained how some systems have screw fractured or fail.

Protocol setting plays and important role in fatigue tests. Factors such as number of loading cycles, angles between loading force and long axis of the implants, and magnitude of the applying force could affect the study results. Study design recommendation for implant fatigue testing have been described under ISO 14801:2007(E) which was prepared by Technical Committee ISO/TC 106, Dentistry, Subcommittee SC 8, Dental implants. However, few studies followed the procedural recommendations. Khraisat, et al. conducted fatigue test showing that internal cone connection implants could sustain more cycles than external hex connection implants\textsuperscript{33}. On the contrary, Ribeiro et al. conducted fatigue test and observed the F50 value was highest for external hex connection implants followed by internal hex and internal conical connection implants\textsuperscript{29}. If the designs of the implant–abutment connections influence the performance of the fatigue resistance is still an open issue. Since other factors such as implant diameters, screw designs, the amount of misfit of the components, and screw torque may also influence the results.

Studies observing maximal bending force of different implant systems suggested that internal conical connection were more resistant fracture\textsuperscript{35, 36, 38–40}. Michalakis, et al. compared bending force between external hex connection implants and internal hex connection implants\textsuperscript{31}. The result showed the external hex connection implants with more bending force resistance. The author suggested the screw bending cause the failure of the abutments. The preload is concentrated in the stem of screw and the preload should ideally be 75% of the ultimate torque to failure to maximize the contact force between the abutment and the implant\textsuperscript{34}.

Abutment screw Torque loss after functional loading could lead to screw loosening, screw fracture, and instability of abutment components. Screw torque loss could be detected after functional loadings in all tested implant systems\textsuperscript{11, 41–48}. Three studies concluded that internal conical connection implants have less torque loss compared with other implant systems\textsuperscript{44, 47, 48}. Larger contact surface area and cold welding effect for internal conical connection may explain this result. However, two studies pointed out that external hex connection implants had less torque loss after loadings\textsuperscript{42, 46}. The author suggested that implant diameters, preload, and screw designs may also influence the torque loss. Abutment should be tightened according to manufacturer’s instructions in order to prevent screw loosening.

Sealing ability may be related to microgap formation between implant abutment connections. The mean microgap was less than 10 um in all tested systems\textsuperscript{15, 22, 27}. Functional loadings may cause greater microgap and microleakage\textsuperscript{16, 20}. Leakage increased in all systems over time and leakage decreased significantly as tightening torque increased to recommended value\textsuperscript{26}. Internal conical connection implants showed less microgap and leakage compared with other connection designs\textsuperscript{14–16, 18, 22, 27}. Studies conducted by Ricomini, et al. found that external hex connection implants had 0%
bacterial penetration. The author hypothesized that the external hexagon present on the implant platform could have act as a physical barrier, possibly impeding the bacteria on the interface penetrated towards the inner part of the implant. To prevent bacterial leakage, one may consider applying conical connection design and tighten the abutment according to manufacturer’s instructions. Repeated insertion and removal of the abutment may lead to removal torque loss\textsuperscript{11, 45}. One should avoid unnecessary removal of abutment in order to prevent future screw loosening.

In order to enhance the clinical parameters, several modifications have been made to the traditional implant connection designs. Cehreli, et al. compared the Periotest value of ITI standard abutments with ITI SynOcta abutments after fatigue loadings. No significant difference in Periotest value was found\textsuperscript{31}. Covani, et al. modified internal hex connection with a collar to improve its stability\textsuperscript{9}. The results showed the internal hex connection with the modification is much more resistant to loosening and distortion than the traditional hex. There are other modifications to traditional connection designs but lack of clinical or laboratory studies to evaluate their efficiency.

**Conclusion**

All of the studies included in this review are in vitro studies. Further efforts should be made on the design of clinical study evaluating the stability of implant–abutment complex among different connection designs. The effects of different modification on implant abutment connection are still inconclusive because there are still not enough studies investigating in this field. Within the limited literature reviewed in this article, we conclude that:

1. **Internal cone connection** seems to have superior sealing ability and minimal micro-gap probably because of the large surface area between the implant fixture and the abutment.
2. **Internal cone connection** have better mechanical performance under bending force.
3. Performances of torque/detorque value and preload in different connection design are still inconclusive.
4. External hex connection tends to have stress concentration at coronal area. Internal hex connection tends to spread force down to fixture tip. Internal cone connection showed more uniformly distributed stresses.

**Reference**

5. Binon PP. Implants and components: entering...
37. Pedroza JE, Torrealba Y, Elias A, Psoter W. Comparison of the compressive strength of


53. Nishioka RS, de Vasconcellos LG, de Melo Nishioka GN. Comparative strain gauge analysis of external and internal hexagon, morse taper, and influence of straight and


比較不同的人工植體支臺齒連接之設計對於支臺齒的穩定度所造成之影響

洪賢晴*,§ 張陽明†,§ 潘裕華‡,§
*,§桃園長庚醫院一般牙科
†台北長庚醫院口腔顱面外科
‡台北長庚醫院一般牙科
§長庚大學

摘  要

本篇系統性文獻回顧目的為比較不同的植體支臺齒連接之設計對於植體支臺齒的穩定度所造成之影響。透過PubMed、Medline (Ovid)、Cochrane Library、Web of Science、Google Scholar等電子資料庫作系統性搜尋。此外還有針對引用文獻做進一步手動搜尋。結果共有53篇文獻被篩選引用於本篇文獻回顧內。所有文獻皆為體外實驗。根據實驗方法以及觀察目標可以進一步分類為(1)密合度(2)疲勞測試之機械性質表現(3)抗彎曲及最大力量乘載(4)螺絲扭力變化(5)壓力分佈等五大類。其結論為：(1)錐形連接有較好之密合度。(2)錐形連接於承受疲勞測試後機械表現较好。(3)對於何種植體支臺齒連接可減少較多螺絲扭力喪失尚無定論。(4)外六角連接易使壓力集中於植體-支臺齒交接處，內六角連接把壓力傳導至植體根尖處，錐形連接把壓力較均勻的分布於植體內。

關鍵詞：植體支臺齒，疲勞測試，錐形連接。