Effect of Posterior Teeth Design And Anterior Teeth Design On Retentive Strength Of Two-piece CAD/CAM Zirconia Implant Abutments From Chewing Force

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บทคัดย่อ
วัตถุประสงค์ของการศึกษานี้ เพื่อประเมินค่าแรงยึดติดและรูปแบบการหลุดจากกันของเรซินซีเมนต์ที่ยึดครอบซับโดยใช้หลักยึดรากเทียมฐานไทเทเนียมและเซอร์โคเนียแบบสองชิ้นจากการจามลองการใช้งานจริงในช่องปากโดยการผ่านอุณหภูมิร้อนเย็นและผ่านแรงบดเคี้ยวต่อการออกแบบเพื่อบูรณะฟันหน้าและฟันหลัง การศึกษานี้ใช้หลักยึดรากเทียมฐานไทเทเนียมทั้งหมด 30 ชิ้นรวมกับครอบซับเรซินที่ออกแบบเพื่อการทดลอง โดยแบ่งเป็นกลุ่มที่ 1) ครอบเซอร์โคเนียล้อมรอบข้าง กลุ่มที่ 2) ครอบเซอร์โคเนียล้อมรอบฟันหน้า กลุ่มที่ 3) ครอบเซอร์โคเนียล้อมรอบฟันหลัง กลุ่มละ 10 ชิ้น ยึดครอบเซอร์โคเนียกับหลักยึดรากเทียมฐานไทเทเนียมด้วยเรซินซีเมนต์ (ариออกส์ ยู200) กลุ่มครอบเซอร์โคเนียเบื้องหน้าและฟันหลังผ่านอุณหภูมิร้อนเย็น กลุ่มละ 10,000 รอบ ที่อุณหภูมิ 5 และ 55 องศาเซลเซียส จากนั้นนำไปผ่านแรงบดเคี้ยวตัวนับ 150 นิวตัน (N) ต่อเนื่อง 1,000,000 รอบ ที่ความถี่ 10 เฮิร์ตซ์ (Hz) จากนั้นเข้าสู่เครื่องทดสอบแรงดึง (universal testing machine;LR30K) ที่ความเร็ว 5 มม./นาที บันทึกค่าแรงดึงที่ครอบเซร์โคเนียหลุดออกจากหลักยึดรากเทียมฐานไทเทเนียมทำให้การวิเคราะห์ข้อมูลที่ได้ด้วยโปรแกรม SPSS 23 (SPSS Inc., Illinois, Chicago, USA) คำสั่งสถิติของแรงยึดติดสูงสุดในแต่ละกลุ่มถูกเรียงลำดับโดยใช้สถิติ One-way ANOVA ที่ระดับความน่าเชื่อถือ 0.95 ผลการศึกษาพบว่าค่าเฉลี่ยและค่าส่วนเบี่ยงเบนมาตรฐานของกลุ่มที่ 1, กลุ่มที่ 2 และ กลุ่มที่ 3 คือ 718.04 ± 164.46 นิวตัน, 625.13 ± 200.11 นิวตัน และ 516.82 ± 191.64 นิวตัน ตามลำดับ จากการศึกษาที่แสดงให้เห็นว่าไม่พบความแตกต่างที่มีนัยสําคัญทางสถิติของค่าแรงยึดติดระหว่างกลุ่ม 3 กลุ่มนี้ (p-value>0.05) กล่าวโดยสรุป คือ กลุ่มควบคุมมีแรงยึดติดมากที่สุดและแรงยึดติดของฟันหลังมากกว่าฟันหน้า แต่อย่างไรก็ตามไม่พบความแตกต่างที่มีนัยสําคัญทางสถิติ

คำสั่งปัญญา: แรงยึดติดด้าน anteriorมีเหตุผล, ไลน์เนียม, หลักยึดรากฟันเทียมชนิด1ชิ้น, เซอร์โคเนีย

Abstract
The purpose of the present in-vitro study was to evaluate the retention force and fracture distribution pattern of two-piece CAD/CAM zirconia implant abutments between a secondary titanium insert and zirconia coping under the artificial aging simulated by using
Thermo-cycling and chewing force on anterior and posterior teeth design. A total of 30 titanium base abutment combined with three different customized design zirconia copings. Group 1) coping control group (n=10), group 2) central incisor coping (n=10), and group 3) mandibular molar coping (n=10). The zirconia coping were bonded to a secondary titanium implant insert using resin-based luting agents (Rely X™ U200). Thermo-cycling was performed in the molar coping group and Incisor coping group up to 10,000 cycles in temperature of 5°C to 55°C. Then the specimens were assigned to be dynamically fatigued in the chewing simulator using Universal testing machine (Intron E1000 All-Electric Dynamic) with a force of 150 N for 1,000,000 cycles at frequency of 10 Hz. The dislodging force of the copings along the long axis of the implant abutment was recorded using a universal testing machine (LR30K) at a crosshead speed of 5 mm/min, and statistical analysis was performed by SPSS 23 (SPSS Inc., Illinois, Chicago, USA) One-way ANOVA. The Results shown that the mean retention values on two-piece CAD/CAM zirconia implant abutment of group1, group3, and group2 were 718.04 ± 164.46 N, 625.13 ± 200.11 N and 516.82 ± 191.64 N respectively. This present study shown that there was no significant difference between the retention values among groups (p-value > 0.05). In the Conclusion, Thermo-cycling and chewing force on both posterior and anterior teeth groups found that the mean retention value of two-piece CAD/CAM abutments was lowered. However, the statistical analysis revealed that this difference was not significant.

Keywords: Retentive strength, Titanium, Two-piece CAD/CAM abutments, Zirconia

Introduction
Replacing missing one or more teeth is clinically important in order to restore the function of masticatory system. Since 1952, Branemark (a Swedish orthopedic surgeon) discovered implants osseointegration and the titanium phenomenon was starting. Over the years, implant-supported fixed (Albrektsson. et al., 2012) dental prosthesis has become an optimum treatment modality for single tooth replacement. (Albrektsson. et al., 2012) Although implant treatments are highly successful, implant-supported restorations are not trouble-free.(Zarb et al., 1990) The success of a dental implant depends on a variety of factors. The anatomic conformation of the osseous structures may suggest placement of implants, and the angulation and position of the teeth adjacent to the edentulous space must also be considered. Because of these limitations, angled or customized abutments have been designed to correct the incongruous angulation of implants.(Dixon et al., 1995) Additional problems have been observed after an implant-supported restoration has been inserted. These implant failures could be due to inaccurate design of the tooth fixture leading to overloading of the abutment screw resulting in abutment screw loosening, abutment screw fracture, damaged abutment screw components and eventually implant fracture. Titanium
has been the dominant implant and abutment material, and long-term clinical studies on titanium have made the outcomes predictable. At the present day, the esthetic result is an important principle for the clinical success of an implant-borne prosthesis. Various materials are available for the fabrication of implant abutments including titanium abutment, ceramic abutment and ceramic abutment with a secondary metallic component or titanium insert. (A. Elsayed et al., 2017)

In a systematic review of metal and ceramic abutments 5-year survival rates were estimated at 97.1% and 99.1% respectively. The most frequent complication was loosening of the abutment screw, which occurred in 4.6%, followed by crown loosening with an incidence of 4.3% and the veneering fracture has a complication rate of 2.7%. (Zembic et al., 2014)

Titanium abutment have excellent biocompatibility and strong material. However, metal components offers many esthetic disadvantages. To solve this problem, improve esthetics and to facilitate technical processing, materials other than titanium, A tooth-like color, good mechanical properties and biological compatibility of zirconia have led to its increased use for various dental applications. Excellent esthetics can be achieved by manufacturing abutments entirely of zirconium dioxide. However, the accuracy of the pure zirconium dioxide abutment connection interface has been questioned, as ceramics cannot be machined as precisely as metals. The implementation of a titanium insert is important to replace the brittle ceramic with metal. (A. Elsayed et al., 2017) A titanium insert enables metal-to-metal contact at the abutment/implant interface, which would result in the same level of precision as all-metal implant systems. It can overcome the brittleness of zirconia and improve the fracture resistance of the abutment. In many recent studies found that zirconium dioxide abutments with titanium inserts demonstrated a greater fracture resistance than pure zirconium abutments. (A. Elsayed et al., 2017; Chun et al., 2015; Yilmaz et al., 2015) The achievement of greater bending moments for computer-aided design (CAD)/computer aided manufacturing (CAM) zirconia abutments with internal connections via a secondary titanium insert than for the ones with one-piece zirconia abutment with external connections. Using a secondary titanium inset might have a beneficial effect on the stability of zirconia abutments (Gehrke et al., 2014; Truninger et al., 2012) and it demonstrated a fracture strength similar to that of titanium abutments and it could be recommended as an esthetic alternative for restorations on single-tooth implants in the anterior region. (A. Elsayed et al., 2017; Butz et al., 2005;
Jimenez-Melendo et al., 2014). Moreover, a secondary titanium insert might seem to be clinically useful for premolar and molar single-tooth replacement.

Resin-based luting agents are considered suitable for attaching the ceramic coping to the titanium insert in case of using two-piece implant abutments. Several bonding systems of titanium and zirconia ceramic have been reported (Edelhoff et al., 2007) but the evidence of the retention between CAD/CAM zirconia copings and secondary titanium inserts in long term are limited, to provide more information about evidence based dentistry and more data for selection of two-piece CAD/CAM zirconia implant abutments on Anterior and posterior teeth. This study investigate the retention forces between the components of two-piece computer-aided design (CAD)/computer aided manufacturing (CAM) zirconia implant abutments bonded to a secondary titanium insert (Jung et al., 2008) under the artificial aging simulated by using thermo-cycling and chewing force on anterior and posterior teeth design.

Material and methods

Specimen fabrication

A total of 30 titanium base abutment (Link-Abutment) (Figure 1) of the Osstem implant system with diameter of 4.5 mm, a height of 5 mm were used. Zirconia copings with a customized design were fabricated by CAD/CAM (Frezarka Robomill 5, ROBOCAM, Germany) from a presintered material (Zenostar Zr Translucent, Germany). The zirconia copings composed of three design (Figure 2); 1) coping control group (n=10), 2) central incisor coping (n=10), and 3) mandibular molar coping (n=10) simplified CAD/CAM crowns with occlusal plane of 15 degrees. The luting gap between the copings and titanium base abutment was adjusted follow the company library setting (75 µm). The analog figure is embedded in PVC ring with self-clear acrylic resin and parallel to long axis of force. Each screw-retained abutment was attached to an implant analog with 30 N.cm. torque using a manual torque controller, following the manufacturers’ instructions.

Cementation

The zirconia coping, ten in each group, were bonded to a prefabricated secondary titanium implant insert using resin-based luting agents: (Rely X™ U200 Self-Adhesive Universal Resin Cement). For all groups, the bonding surfaces of the titanium inserts was air-abraded with 50 µm aluminum-oxide particles at 2.0 bars pressure (0.25 MPa) for 20 seconds at a distance of 10 mm. (Gehrke. et al., 2014) after that they were cleaned in alcohol. All specimens were cemented by the same operator, The coping were seated with a load of 5 kg to be applied along the long axis of the abutment for a 10-minute period (Gehrke. et al., 2014), hold together and pre-polymerize with a light curing unit following the manufacturers’ instructions.
After cementation all specimens were stored in deionized water (37°C) for 3 days. After 3 days of storage, specimens were subjected to the treatment proposed by each experimental subgroup. The control group (no thermo-cycling, no chewing force) (n=10) specimens were overall stored in deionized water for 3 days. Thermo-cycling was performed with Molar coping group and Incisor coping group being subjected to 10,000 cycles (Gale et al., 1999) from 5°C to 55°C with a dwell time of 20 seconds followed International Standards Organization, 1994.(Morresi et al., 2014) After that the specimens are assigned to be dynamically fatigued in the chewing simulator are subjected to dynamic loading test by Universal testing machine (Intron E1000 All-Electric Dynamic) with a force of 150 N was applied. 1,000,000 cycles at frequency of 10 Hz.(Gratton et al., 2001)

The molar coping group specimens were fixed on a loading platform at parallel with long axis, and cyclic fatigue loading is applied to the tapered occlusal area of each molar simplified crown with a round stainless steel stylus with a diameter of 3.5 mm.(Gehrke. et al., 2015) For incisor coping group specimens were fixed on a loading platform at 30-degree to long axis, and cyclic fatigue loading was made contact with the specimen 2.0 mm from the incisal tip to simulate maxillary anterior tooth contact, as modified from the ISO 14801 standard, For this purpose, a special setup was designed to accomplish the dynamic loading process. The implant analogs were attached firmly in a holder, which is again placed in a specially designed holder. For dynamic loading purposes, the holder is placed into the water chamber of the chewing simulator and screwed tightly into position at temperature of 37°C. All specimens were subjected to a pull out test using a universal testing machine (LR30K) at a crosshead speed of 5 mm/min.(Gehrke. et al., 2014) Type of failure mode is recorded. The failure modes were as follows: (i) Adhesive fracture only between zirconia surface and resin insert (ii) Adhesive fracture between zirconia surface and resin as well as between titanium surface and resin (Mixed) and Record the maximum load (N) at break cement between secondary titanium insert abutment and zirconia coping and calculated the mean value in each group. Means and standard deviations of retention at failure were analyzed. One-way ANOVA was used for data analysis.
Figure 1 Components of the test specimens: titanium base abutment

Figure 2 Zirconia coping customized for pull-off testing: a. no thermo-cycling and no chewing (control group), b. anterior tooth design group, c. posterior teeth design group

Figure 3 Final installation of test specimens. Laboratory implant fixed in acrylic block. Titanium base fixed into the laboratory implant by holding screw. Zirconia coping connected to the titanium base by using resin-based luting agent.
Figure 4 Test set-up thermo-cycling 10,000 time between 5°C to 55°C for artificial aging of bond interface.

Figure 5 Anterior teeth dynamic loadinf setup in chewing chamber.

Figure 6 Posterior teeth dynamic loading setup in single chewing chamber.
Results

The individual retention values, means, and standard deviations are summarized in (Table 1). The mean retention values of no chewing force with no thermos- cycling group (control) were 718.04±164.46 N which showed the highest value among study groups. The mean retention value of posterior teeth design on two-piece CAD/CAM zirconia implant abutment (625.13±200.11 N) was higher than Anterior teeth design on two-piece CAD/CAM zirconia implant abutment (516.82±191.64 N). One-Way ANOVA indicated no significant difference between the retention values of the tested groups (p = 0.071)(Table 1). The distribution of fracture in group1 (no thermo-cycling, no chewing force) were considered as adhesive fracture between zirconia surface and resin insert to 5 specimens (Figure 9) and the mixed failure (adhesive fracture between zirconia surface and resin as well as between titanium surface) was found 5 specimens (Figure 10). In group 2, 3 mixed failure were high up to 9 specimens, while adhesive fracture was low for 1 specimens in each group (Figure 3). This fracture distribution indicates that the bonding between the zirconia surface and resin is the weak point of specimen that didn’t pass the aging and chewing force. The remaining two group which passed thermo-cycling and chewing force, the weak points are at zirconia surface and resin as well as between titanium surface and resin.
Table 1. Individual Retention Minimum/Maximum Values, Mean, and Standard Deviations of Two-piece CAD/CAM Zirconia Copings to Titanium Inserts for Different Test groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (N)</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. no thermo-cycling no chewing force</td>
<td>718.0</td>
<td>164.4</td>
<td>391.6</td>
<td>917.7</td>
</tr>
<tr>
<td>2. Incisor Coping a</td>
<td>516.8</td>
<td>191.6</td>
<td>142.2</td>
<td>710.5</td>
</tr>
<tr>
<td>3. Molar Coping b</td>
<td>623.6</td>
<td>200.1</td>
<td>330.1</td>
<td>948.3</td>
</tr>
</tbody>
</table>

*a=Anterior teeth design on titanium base implant abutment with thermos-cycling 10,000 cycle and chewing force 1,000,000 cycle

*b=Posterior teeth design on titanium base implant abutment with thermos-cycling 10,000 cycle and chewing force 1,000,000 cycle

Figure 8 Bar graph diagram show values of mean retention force in Newton.
Table 2. Distribution of Fracture Patterns

<table>
<thead>
<tr>
<th>Group</th>
<th>Adhesive fracture between Zirconia surface and Resin</th>
<th>Adhesive fracture between Zirconia surface and Resin as well as between titanium surface and resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. no thermo-cycling, no chewing force</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
| 2. Incisor Coping  
*a* | 1                                                   | 9                                                                                               |
| 3. Molar Coping  
*b* | 1                                                   | 9                                                                                               |

*a* = Anterior teeth design on titanium base implant abutment with thermos-cycling 10,000 cycle and chewing force 1,000,000 cycle

*b* = Posterior teeth design on titanium base implant abutment with thermos-cycling 10,000 cycle and chewing force 1,000,000 cycle

Figure 9 Distribution of Fracture Patterns: adhesive fracture between Zirconia surface and Resin

Figure 10 Distribution of Fracture Patterns: adhesive fracture between Zirconia surface and Resin as well as between titanium surface and resin
Discussion

Zirconia abutments are commonly used in implant dentistry, because of its esthetic and biological advantages. Recent studies have shown that one-piece zirconia abutments have a marginal misfit to the implant that might cause screw loosening, wear of the implant-abutment interface and increased size of the marginal gap leading to bacterial colonization. Therefore, the use of a secondary titanium component, bonded to a zirconia coping, has been recommended. For these two-piece implant abutments, resin-based luting agents are considered suitable for attaching the ceramic coping to the titanium insert (Gehrke. et al., 2014). However, limited data are available on the retention of CAD/CAM zirconia copings on secondary titanium inserts.

Long-term water storage at a constant temperature and long-term thermal cycling are often used to simulate aging of resin bonds. In this study 1 year artificial aging was combined with thermal cycling and chewing force by fatigue loading to test long-term durability of the retention of industrial manufactured stabilized zirconia ceramic copings bonded to titanium abutments using a dual-cure resin cements (RelyX™ U200, 3M ESPE, Germany). The present study investigated the retention forces between the components of two-piece CAD/CAM zirconia implant abutments bonded to a secondary titanium insert under the artificial aging simulated by using thermo-cycling and chewing force on anterior and posterior teeth design. The results of this study showed that there was no significant difference in retentive strength among three groups, rejecting the working hypothesis. Although the mean retention values among groups were not statistically significant difference \( (p = 0.071) \) (Table 1), the mean retention of control group (no thermo-cycling, no chewing force shown) posed highest retentive value followed by molar coping and incisor coping group respectively. This might be caused by the difference of direction of the dynamic loading that acted upon molar coping design and incisor coping design. For molar coping group, specimens were fixed on a loading platform parallel to long axis, and cyclic fatigue loading was applied to the occlusal area of each molar specimens simulating the vertical occlusal force stimulation. For incisor coping group specimens were fixed on a loading platform at 30-degree to long axis, and cyclic fatigue loading was made contact with the specimen 2 mm. from the incisal tip to simulate maxillary anterior tooth contact, as modified from the ISO 14801 standard. For both molar coping and incisor coping group, there were no complications such as screw loosening, screw fracture, and abutment fracture. Even at a processed of 1,000,000 cyclic fatigue loading cycle represented as 1 year clinical use, crown loosening was not found. However, in this in vitro study the limitation are design of the study that cannot reinterpreted before and after in the same specimens because of some zirconia coping fracture at margin after pull-off, so their outcomes should be interpreted with caution. Furthermore, stability and success rate of implant abutments are multifactorial factors. Once should evaluated all of these factors together.
Analysis of Fracture Patterns in previous study (von Maltzahn et al., 2016) indicates that the bonding between the zirconia surface and the resin is the weakest point of the construction. When compare with present study which included chewing force or dynamic loading as another factor, the result of fracture patterns demonstrated that the weak point of two-piece zirconia implant abutment were adhesive fracture between zirconia surface and resin cement as well as between titanium surface and resin. Although in vitro studies, such as this study, was set as nearly as clinical situation, outcomes from these should be interpreted with caution. In addition to the functional aspects of implant abutments, the biocompatibility of dental material is increasingly gaining significant attention from both patients and dentists. Although these results cannot be directly concluded to the clinical situation, the potential incident of adverse effects caused by the design of crown on implant abutment and the direction of chewing force showed to have an effecting retentive strength between crowns and implant abutment in long-term clinical situation. Hence, the dentist should be careful when making clinical decisions. Further research evaluating the potential cytotoxic, genotoxic, or carcinogenic risks of resin-based cements for two-piece implant abutments are necessary

Suggestions

Two-piece CAD/CAM zirconia implant abutments might be clinically beneficial in anterior and posterior area of single tooth replacements. Although these results showed that the direction of chewing force to have an effecting retentive strength between crown and implant abutment in long-term clinical situation, but the value was not statistically significant difference.

For more information, the future study should be more sample size and increase cyclic loading and thermos-cycling to evaluated long term durability in 5 or 10 years clinical use.

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