Influence of Abutment Geometry on Zirconia Crown Retention: An In Vitro Study

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Influence of Abutment Geometry on Zirconia Crown Retention: An In Vitro Study

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The Master's Thesis
Submitted to the Department of Dentistry and
the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Master of Dental Science

Bayandelger Davaatseren

December 2024

**This certifies that the Master's Thesis of
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**The Graduate School
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December 2024**

Acknowledgement

이 논문을 완성하기까지 아낌없는 배려와 세심한 지도로 이끌어주신 이재훈 교수님께 깊은 존경의 마음과 감사의 말씀을 드립니다. 교수님의 신앙과 그로부터 받은 지혜는 제가 연구하는 데 많은 힘이 되었습니다. 또한 제 연구 과정을 통해 지속적으로 지도해주시고 관심을 주신 모든 교수님들께도 감사의 말씀을 전합니다. 연세대학교에서의 수업을 가르치시는 교수님들께서 학문적 이론과 임상 경험을 조화롭게 결합하여 정말 흥미롭게 강의를 진행하시는 모습을 보며, 때로는 수업이 끝나지 않았으면 좋겠다는 생각이 들 때도 있습니다.

특히, 저를 항상 지지하고 격려해주신 가족에게 감사의 마음을 전하고 싶습니다. 제가 몽골에서 이곳으로 와서 치과 보철학 석사 과정을 공부하는 동안 언제나 큰 힘이 되어준 남편과, 사랑스러운 두 딸에게도 깊은 사랑과 감사를 보냅니다.

새로운 시작을 할 수 있는 기회를 준 모든 분들께 또 한 번 감사의 말씀을 드립니다.

2024 년 12 월

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This in vitro study investigated the retention of three different geometrical designs of short Ti-base abutments used in implant-supported zirconia crowns. The advent of digital technology has facilitated the use of Ti-base abutments in implant dentistry, offering improved time efficiency, precision, and patient comfort. Ti-base abutments, known for their hybrid design and retrievability, are increasingly preferred for their compatibility with CAD/CAM systems and their ability to support both monolithic and bilayered zirconia restorations. However, the influence of abutment geometry on retention remains under-researched.

The study evaluated three types of short Ti-base abutments: Geo SRN multibase (Group A), Herilink (Group B) and TS Link (Group C) each with a height of 4 mm and gingival height of 1 mm (n = 20/group). Zirconia crowns were modified for the test set up and fabricated using CAD/CAM technology and bonded to the abutments with RelyX Luting 2 Resin Modified Glass Ionomer Cement. The specimens underwent pull-out tests at a crosshead speed of 1 mm/min to assess retention. One-way ANOVA and post hoc Tukey test were used for statistical analysis. The statistical analysis revealed significant differences in the retention values among the different abutment shapes ($p < 0.05$). The hexagonal-shaped Ti-base abutment showed the greatest force at 360.20 N. The retentive force of the circumferential Ti-base implant abutment increased from 194.65 N for Group A to 241.33 N for Group C. The retention of zirconia crowns was influenced by the geometrical design of the abutments, with hexagonal shapes demonstrating superior retention characteristics. The study concludes that the geometric form of Ti-base short abutments significantly affects the retention of CAD/CAM zirconia crowns. These findings provide valuable insights for clinicians in selecting the most appropriate abutment design to enhance the success of implant-supported restorations.

Keywords: short Ti-base abutments, abutment geometry, abutment configuration, CAD/CAM, zirconia crowns, pull-out test, implant dentistry, retention, in vitro study.

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I. INTRODUCTION

Implant-supported restorations are a dependable treatment option for dentists when dealing with a single missing posterior tooth [1]. Advancements in implant design, surface treatments, prosthetic materials, and surgical guidance have significantly improved the survival rates of dental implants [2]. A systematic review has reported survival rates of over 97% across all placement and loading protocols [3]. Additionally, reviews suggest a 97.6% survival rate for single-implant restorations without complications after three years [4].

Various materials are available for the fabrication of implant-supported single crowns [5]. In implant treatment, titanium abutments paired with porcelain-fused-to-metal (PFM) crowns are considered the gold standard, boasting a five-year survival rate of approximately 98.3% [6]. To enhance aesthetics, zirconia-based restorations have been introduced [7]. Monolithic zirconia, manufactured using Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM), offers high biocompatibility and reduces plaque accumulation [8]. In the posterior region, where high occlusal forces are present, materials with strong fracture resistance are essential. Zirconia has consistently proven effective for abutments and implant restorations in these areas and offers a similarly effective alternative to PFM crowns for restoring single implants in the posterior region [9].

Implant prostheses are typically fixed to standard or custom abutments using either screws or cement [10, 11]. Cement-retained restorations offer superior aesthetic by eliminating the need for a screw hole, which also removes the need for composite resin repairs and allows for more effective ceramic layering. These restorations are also believed to withstand occlusal forces better due to the enhanced ceramic layering. Cement-retained restorations are often preferred when implants are placed at an angle that deviates from the ideal prosthetic axis [11]. However, a major drawback of cement-retained restorations is the difficulty in removing excess cement from the gingival sulcus, which can lead to peri-implantitis and make the restoration irretrievable [12-14]. On the other hand, screw-retained restorations offer the advantage of retrievability and avoid biological complications related to cementation. Screw-retained crowns are associated with fewer pathogenic bacteria compared to cemented crowns, which had more inflammatory cells and a higher presence of periodontal pathogens [15].

Currently, digital technology is playing an increasingly important role in oral implantology. Computer-aided technology has transformed dentistry by providing efficient and precise methods for creating various restorations, including implants. The rise of digital workflows in dentistry has led to a growing interest in Ti-base abutments, which are designed with geometry stored in CAD/CAM systems for efficient restoration fabrication [16]. These advancements have enabled a fully digital workflow in oral rehabilitation, where intraoral scanning and CAD/CAM technology allow for faster, more precise processes, improving time efficiency by around 50% and ensuring highly accurate prosthetic reconstructions [17, 18]. The digital impression scanning also eliminates the need for traditional alginate or silicone rubber impressions, avoiding patient discomfort such as nausea and gagging. Ti-base abutments are compatible with CAD/CAM, allowing for the quick creation of well-fitting prostheses.

Ti-base abutments are pre-made titanium components with a hybrid design that allows both cemented and screw-retained fixation within a single prosthesis [19, 20]. These abutments connect either to monolithic customized crown or to a high-strength customized ceramic abutment with a cement-retained crown (a three-piece screwed restoration) [21]. This hybrid retention mechanism makes it easier to remove excess cement and ensures improved light curing of the restoration margins before screwing in the final restoration. CAD/CAM-generated restorations, such as a zirconia crowns or abutments, can be cemented onto these abutments, enhancing both their versatility and reliability. One of the key advantages of Ti-base abutments is their retrievability. Like UCLA abutments and other screw-retained systems, Ti-base abutments allow the abutment-crown assembly to be cemented outside the mouth, ensuring excess cement is removed to prevent peri-implantitis before final screw fixation [13] . Furthermore, CAD/CAM systems now include comprehensive libraries for the rapid fabrication of prostheses using Ti-base abutments [20].

The selection and cementation protocols for Ti-base abutments vary, and choosing the right abutment is crucial to the success of implant treatment. Many companies now offer Ti-base abutments specifically designed for digital dentistry. Manufacturers have improved the geometry and design of these abutments to enhance retention, making even short abutments a viable option for restoring edentulous spaces. The retention of the final prosthesis is influenced by several factors, including the height of the Ti-base, the surface texture, the type of cement used, the fit of the superstructure, and any surface treatments applied [20]. Achieving adequate retention with short abutments remains a challenge, and companies provide various abutment designs for digitally created prostheses. However, there is currently limited research on the geometric differences among the various types of Ti-base abutments.

This study aims to compare the retention of three different shapes of short Ti-base abutments for implant crown restoration. The primary objective is to test the hypothesis that the shape of the abutments significantly affect the retention of CAD/CAM zirconia crowns. This research intends to provide valuable insights for clinicians in selecting the most appropriate implant abutment, ultimately improving the success of implant-supported restorations in cases with limited vertical space.

II. MATERIALS AND METHODS :

1. Sample Preparation:

In this in vitro study, 60 test specimens were evaluated using three distinct types of short Ti-base abutments (n = 20/group). Figure 1 illustrates the specimens used in this experiment. These abutments were divided into three groups based on their shape:

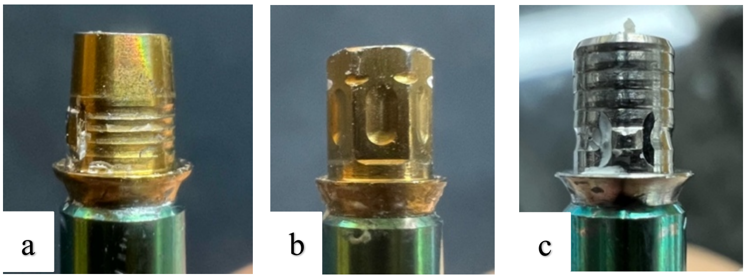

Figure 1. Specimen illustration used in this experiment

a: Group A - Diameter 4.5 mm, abutment height 4mm, gingival height 1.2 mm. This group features a cylindrical shape that slightly tapers in the second half from the midpoint. The lower part has grooves around the cylindrical surface, and there is a rectangular ledge protruding from the abutment surface (Geo SRN multibase abutment, Geo Medi, Seoul, Korea).

b: Group B - Hexagonal shape with across flats (WAF) of 4 mm, abutment height 4 mm, gingival height 1.3 mm, and a 0° convergence angle. The hexagonal cylinder features rectangular dimples on each face and grooves at the top of the vertices (Herilink abutment, Heri Implant, Seoul, Korea).

c: Group C - Diameter 4.5 mm, abutment height 4 mm, gingival height 1 mm, with a 0° convergence angle. This group features a cylindrical shape with numerous grooves around the abutment surface and there is a rectangular ledge located just above the flat form (TS Link abutment, Osstem, Seoul, Korea).

Ti-base abutments were screwed to an implant analog (GSTLA400, TS Fixture Lab analog, Osstem) and tightened to the manufacturer recommended torque of 30 Ncm using a torque wrench. All screw channels were closed with Teflon tape.

2. Scanning and Crown Fabrication:

Zirconia copings were modified for the test setup. Each group of abutments was scanned using a desktop scanner (E1 3shape TRIOS 3D model scanner, Denmark) and design using software (Dental System Premium, 3Shape, Denmark). Figure 2 and 3A show the three-dimensional design. The superstructure was planned as a spherical-shaped zirconia coping with height of 7.5mm, a width of 9mm, and a diameter of 6mm. The cement gap was set at 40µm, which is similar to the values used in clinical settings. The test specimens were milled from a zirconia disc (LUXEN Smile S2 zirconia block, DentalMax, Korea) and subsequently sintered at 1350°C for 7 hours. The marginal fit was evaluated under 4x magnification.

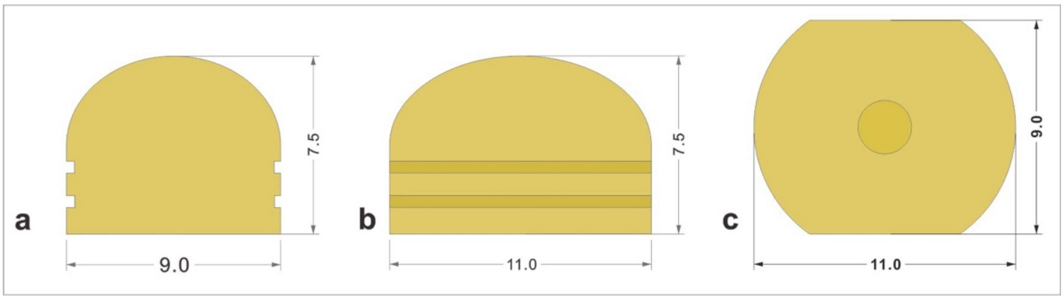

Figure 2. Modified zirconia coping diagram used in this experiment
(a) Frontal view; (b) Lateral view; (c) Lower view of zirconia coping

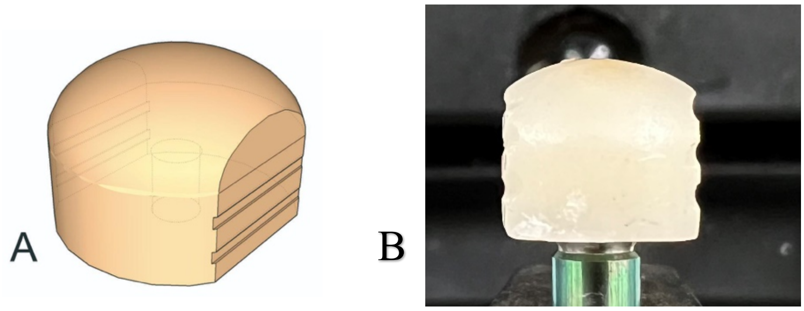

Figure 3. (A) Three-dimensional design of modified zirconia coping;
(B) the fabricated zirconia coping

3. Cementation:

CAD/CAM-generated zirconia copings, as shown in Figure 3B, were bonded to geometrically different abutments using RelyX Resin Modified Glass Ionomer Cement (3M ESPE, St Paul, MN, USA). All specimens were cemented by the same operator, following the manufacturer`s instructions. The specimens were then stored at room temperature for 30 minutes until the complete setting reaction had occurred. After the setting period, all excess cement was removed with an explorer, and each surface was polymerized for 60 seconds.

4. Pull out test:

The specimens were assembled, as shown in Figure 4, in a Universal Testing Machine (5942 Model, Norwood, MA, USA) and subjected to a pull-out test (retention) at a crosshead speed of 1 mm/min. The force required to remove the copings was recorded in newtons and tabulated for statistical analysis. (Figure 5)

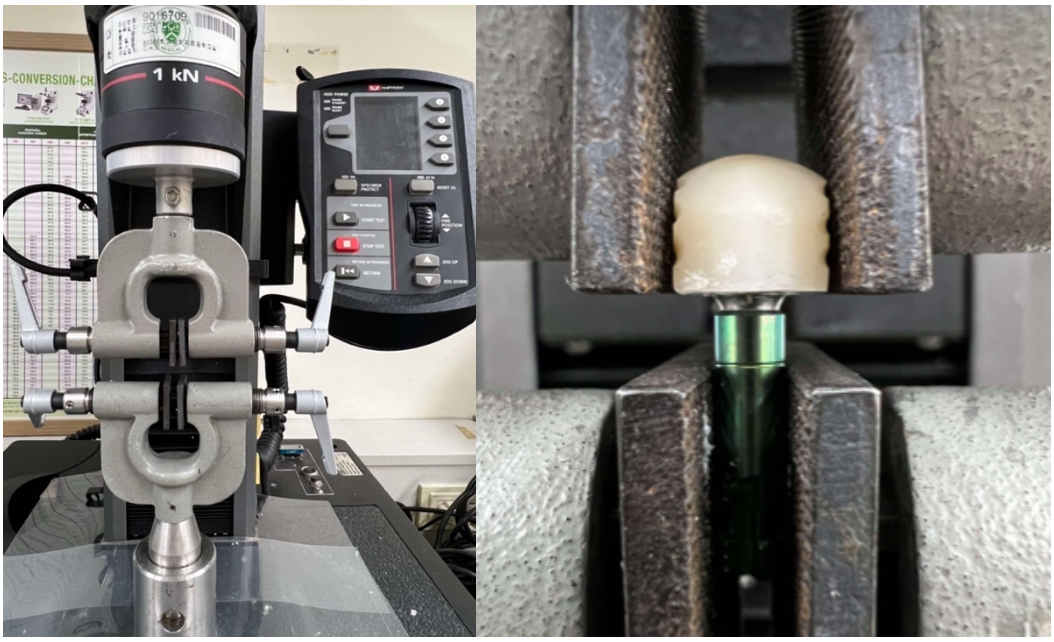

Figure 4. Universal Testing Machine (5942 model, Norwood, MA, USA) used for measuring pull-out force at a crosshead speed of 1 mm/min in this experiment

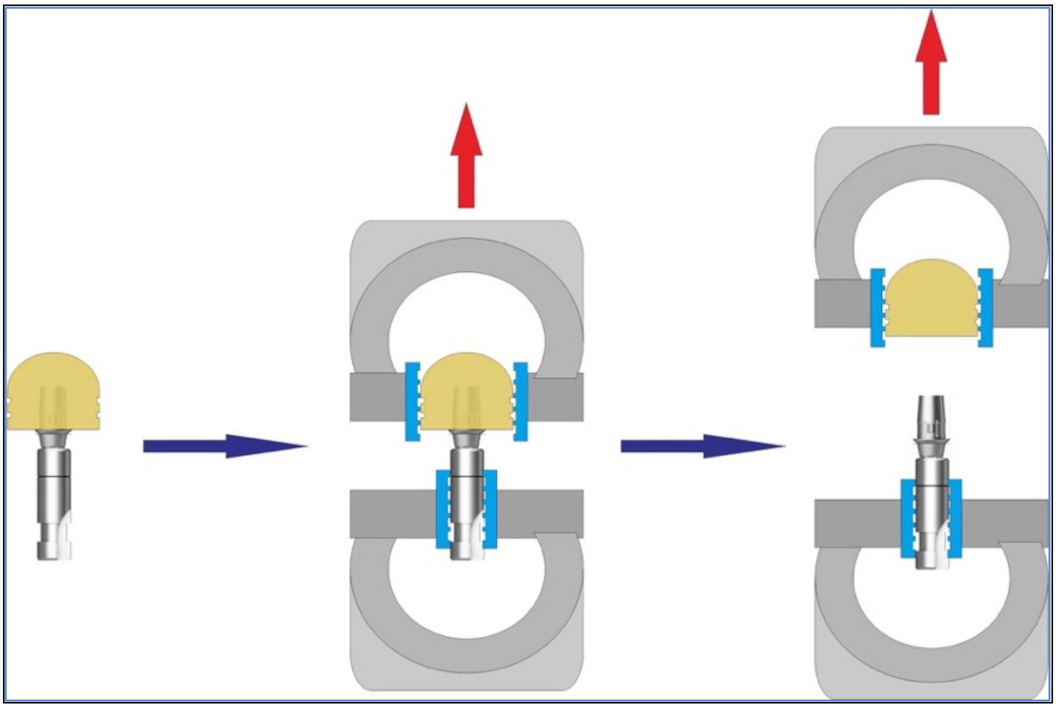

Figure 5. Experimental Design: Ti-Base abutment and zirconia crown design attached for the pull-out test to measure retentive strength

5. Statistical analysis:

Statistical analysis was performed using IBM SPSS software, version 29.0.

The data were subjected to a one-way ANOVA and post hoc Tukey`s HSD test.

Statistical significance was determined with a p-value less than 0.05 ($p < 0.05$).

III. RESULTS

The mean tensile force required to separate the copings from the abutments is shown in Figure 6. Statistical analysis, including one-way ANOVA and post hoc tests, revealed significant differences in removal force between the groups with different abutment shapes ($p < 0.01$) (Table 1). The hexagonal-shaped Ti-base implant abutment in Groups B demonstrated a statistically significant difference compared to the circumferential-shaped Ti-base implant abutments in Groups A and C ($p < 0.01$), indicating superior retention (Table 2). However, there was no significant difference between Groups A and C ($p = 0.106$) (Table2). The hexagonal-shaped Ti-base abutment had the highest retention force at 360.20 N, while the circumferential Ti-base implant abutment showed an increase in retention force from 194.65 N in Group A to 241.33 N in Group C. The addition of grooves increased the retention values from an average of 194.65 N to 241.33 N.

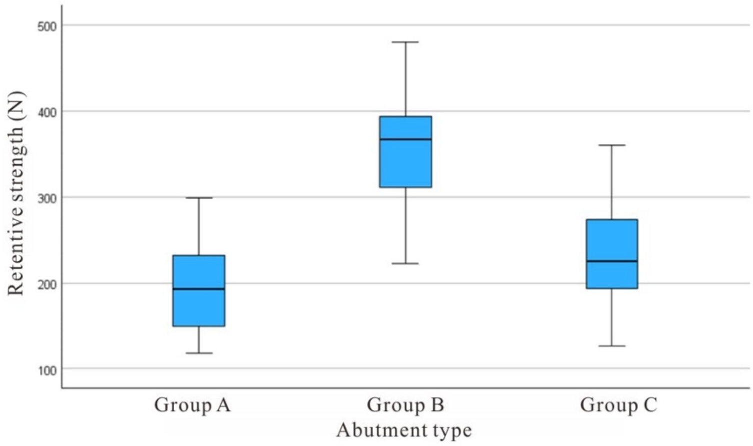

Figure 6. Box-plot diagram showing the retention strength of different abutment groups (in Newtons)

Table 1. Oneway ANOVA test

Oneway ANOVA

data	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	291448.65	2	145624.32	28.504	<.001

Table 2. Post Hoc Tests

Group	**Mean difference**	**Standard error**	**Sig.**	**95% confidence interval**	
				Lower bound	Upper bound
Group (B – A)	165.55	22.61	<.001	111.14	219.96
Group (B – C)	118.86	22.61	<.001	64.45	173.27
Group (A – B)	46.68	22.61	.106	7.72	101.09

*. The mean difference is significant at the 0.05 level.

IV. DISCUSSION

In the present study, retention forces varied among the three tested abutments. Therefore, the first null hypothesis, which suggested that there would be no significant differences in retention among short Ti-Base abutments of different shapes, was rejected. The hexagonal shaped Ti-Base abutment demonstrated a higher pull-out force compared to the circumferential shaped Ti-Base abutment. The long-term success of implant-supported restorations depends on several factors, including abutment design, taper angle, height, texture, cement type, and surface pretreatment [22]. Selection of the appropriate abutment is crucial in preventing complications with implant-supported restorations. One main advantage of Ti-Base abutments, as previously mentioned, is the ability to perform the bonding procedure before crown placement.

In terms of abutment height, 4 mm short abutments were used in this study. Using short titanium base abutments in the posterior region is often recommended due to the limited interocclusal space commonly found in edentulous patients. The reduced space in this area can make it challenging for dentists to achieve optimal retention for prostheses. Short Ti-base abutments help address this issue by providing a more practical solution for securing restorations in cases where vertical height is limited, ensuring better stability and retention without compromising the prostheses design. The hexagonal Ti-base abutment, with retentive elements and 4 mm height, increased the retention of the zirconia restoration. If the available restorative space allows for the use of Ti-Base abutments taller than 4mm, a taller abutment is recommended to improve retention. However, in cases where the restorative space is limited, a 4 mm abutment may be necessary. Knowing the minimum height requirement for Ti-base abutments can be valuable during pre-surgical planning to ensure there is enough vertical space to accommodate this minimum height. Previous studies have shown that abutment height can influence the retention of implant-supported restorations, though result have been inconsistent. One study found that crown material and Ti-base height had a significant effect, but their interaction was not significant [23]. Increasing the height of Ti-Base abutment significantly improves the retention of zirconia restoration [22]. However, some researchers indicated that abutment height has less impact on retention than the abutment geometry [24].

Few studies considered about the geometric aspect of an implant abutment. The geometric shape of an abutment has an crucial role in retention besides bond forces and micro retentive forces [25]. Adding circumferential grooves to implant abutments increased the retention of cement-retained restorations [26]. Manufacturer is important; for both Zr- and Ti-base abutments, parts from different manufacturers, design, and manufacturing differences influenced performance and appeared extremely similar on clinical examination. Finally, design defects/problems were suggested for all systems. The manufacture matters; differences in design and fabrication that influence performance cannot be discerned clinically [27].

In this study, the cement gap size was set to 40 μm. Increasing the cement gap from from 30 to 60 μm negatively impacted cement durability [28]. Increasing the cement gap from 10 to 50 μm significantly reduced the pull-off force of implant-supported crowns [29]. Most studies recommend a cement thickness of 30 to 40 μm to ensure complete seating of the restoration. Based on this, a cement gap of 40 μm was selected for this study, with permanent cement.

The height of the abutment and convergence angle play critical role in the retrievability of prostheses. Studies have shown that as the convergence angle increases while abutment height remains constant, removal torque values decrease significantly [30]. These findings align with previous research highlighting the impact of abutment height and surface area on prosthesis retention. It is also crucial to consider the surface area and total occlusal convergence (TOC) of the abutments, as these factors greatly influence the retention of cement-retained prostheses. Research indicates that maximum retention in full-veneer crowns is achieved with parallel axial walls, while retention decreases substantially as the TOC angle increases [31]. Additionally, another study found that cylindrical preparations with a 20-degree TOC provide greater retention compared to those with a 30-degree [32].

The limitations of this study include its in vitro design, which allows for the evaluation of specific variable that is geometric design. Although uniaxial pull-out retention tests do not perfectly replicate intraoral conditions, they are an efficient alternative for determining the retentive force between an abutment and a zirconia restorations. Based on this study, it can be interfered that all tested groups could withstand average physiological occlusal forces typically exerted in the posterior molar region. However, intraoral occlusal forces are dynamic rather than static. In vitro studies, such as this one, cannot fully substitute clinical trials, and their result should be interpreted with caution. Further, in vitro and clinical studies are necessary to determine a universal abutment selection protocol for optimal restoration retention.

V. CONCLUSION

The purpose of this study was to assess how different geometric variations in the dental implant Ti-base abutments influence the retention of cemented implant-supported prostheses. The hexagonal shape of the Ti-base abutment could be increased the retention of implant-supported prosthesis. Additionally, the geometrical design of the abutments affected the retention of zirconia crowns, with some shapes showing better retention characteristics than others. When interocclusal space is limited, a hexagonal Ti-base is recommended due to its enhanced retention.

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ABSTRACT (in Korean)

지르코니아 크라운 유지력에 대한 어버트먼트 형태의 영향: In vitro 연구

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다와세렝 바양델게르

본 연구의 목적은 임플란트 지지형 지르코니아 크라운에 사용되는 세 가지 서로 다른 형태의 짧은 Ti-base 어버트먼트의 유지력을 조사하는 것 입니다. 디지털 기술의 발전으로 Ti-base 어버트먼트는 치과 임플란트 분야에서 시간 효율성, 정밀도 및 환자 편안함을 향상시키는 장점을 제공하며, 하이브리드 디자인과 회수 가능성으로 CAD/CAM 시스템과의 호환성 및 일체형 및 이중층 지르코니아 보철물을 지지하는 능력으로 인해 점점 더 선호되고 있습니다. 그러나 어버트먼트 형태가 유지력에 미치는 영향에 대한 연구는 미흡한 실정입니다. 본 연구에서는 높이 4mm 를 가지는, 세 가지 유형의 짧은 Ti-base 어버트먼트 Geo SRN multibase (A 그룹), Herilink (B 그룹), TS Link (C 그룹), 각 군당 n=20)를 평가했습니다. CAD/CAM 기술을 이용하여 제작된 지르코니아 크라운을 RelyX 레진 글래스 아이오노머 시멘트를 사용하여 어버트먼트에 접착했습니다. 시편은 1mm/분의 교차 헤드 속도로 인장 시험을 실시하여 유지력을 평가하였습니다. 통계 분석에는 One-way ANOVA 과 Post Hoc Tukey test 를 사용했습니다. One-way ANOVA 과 Post Hoc Tukey test 결과, 어버트먼트 형태에 따라 유지력에 유의미한 차이가 있는 것으로 나타났습니다 ($p < 0.05$). 육각형 형태의 Ti-base 어버트먼트가 가장 큰 유지력(360.20 N)을 보였습니다. 원통형 Ti-base 임플란트 어버트먼트의 유지력은 홈이 추가됨에 따라 A 그룹 194.65 N 에서 C 그룹 241.33 N 으로 증가했습니다. 지르코니아 크라운의 유지력은 어버트먼트의 형태에 영향을 받았으며, 육각형 형태가 우수한 유지 특성을 보였습니다. 본 연구는 짧은 Ti-base 어버트먼트의 형태가

CAD/CAM 지르코니아 크라운의 유지력에 상당한 영향을 미친다는 결론을 내렸습니다. 이러한 결과는 임플란트 지지형 보철물의 성공률을 높이기 위해 가장 적절한 어버트먼트 디자인을 선택하는 데 임상의에게 유용한 정보를 제공합니다.

핵심 되는 말: 짧은 Ti-base 어버트먼트, 제한된 구치부 공간, 어버트먼트 형태, 어버트먼트 구성, CAD/CAM, 지르코니아 크라운, 치과 임플란트, 유지력, in vitro study