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지르코니아와 레진나노세라믹 임플란트 지대주의 두께에 따른 열순환 후 파절저항

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Fracture resistance of zirconia and resin nano ceramic implant abutments according to thickness after thermocycling

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Purpose: The aim of this *in vitro* study is to investigate load bearing capacity of esthetic abutments according to the type of material and wall thickness. **Materials and methods:** 70 specimens equally divided into seven groups according to their abutment wall thicknesses. The abutments prepared with titanium 0.5 mm wall thickness were used as a control group (Ti-0.5), whereas zirconia abutments and resin nano ceramic abutments with wall thickness 0.5 mm, 0.8 mm and 1.0 mm were prepared as test groups (Zir-0.5, Zir-0.8, Zir-1.0 and RNC-0.5, RNC-0.8, RNC-1.0). All specimens were tested in a universal testing machine to evaluate their resistance to fracture and all of them underwent thermo-cycling before loading test. Mean fracture values of the groups were measured and statistical analyses were made using two-way ANOVA. **Results:** Zir-1.0 showed the highest mean strength (2,476.3 ± 342.0 N) and Zir-0.8 (1,518 ± 347.9 N), Ti-0.5 (1,041.8 ± 237.2 N), Zir-0.5 (631.4 ± 149.0 N) were followed. The strengths of RNC groups were significantly lower compared to other two materials (RNC-1.0 427.5 ± 72.1, RNC-0.8 297.9 ± 41.2) and the strengths of all the test groups decreased as the thickness decreases ($P < .01$). RNC-0.5 (127.4 ± 35.3 N) abutments were weaker than all other groups ($P < .05$). **Conclusion:** All tested zirconia abutments have the potential to withstand the physiologic occlusal forces in anterior and posterior regions. In resin nano ceramic abutments, wall thickness more than 0.8 mm showed the possibility of withstanding the occlusal forces in anterior region. *(J Korean Acad Prosthodont 2017;55:144-50)*

Keywords: Nano ceramics; Dental abutment; Load-bearing capacity; Zirconia; Fracture

Introduction

To overcome the esthetic problems and to comply with clinician's and patient's increased demands for highly esthetic results, ceramic abutments started to be developed.

Ceramic abutments for dental implants have been in clinical use since early 1990s.[1] At first, the abutments were made of the densely sintered high-purity alumina (Al_2O_3) which in some studies showed good survival rates.[2,3]

Zirconia abutments are successors to alumina (Al_2O_3) abutments. Compared with the former, zirconia abutments are radiopaque and demonstrate significantly higher resistance to fracture property. Some studies had reported that the flexural strength (900 - 1200 MPa) of yttrium-stabilized zirconium oxide is three times that of pure aluminum oxide,[4,5] and it's fracture toughness (9 - 10 MPa $m^{1/2}$) is 2 times as high whereas Young's modulus registers only half of the aluminum oxide values.[4,6] The clinical outcome and survival rate of zirconia abutments have shown better reliability *in vitro* and *vivo* studies and also been comparable to those observed for titanium abutments in all area including molar substitutes.[7,8]

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Today, the majority of implant manufacturers offer zirconia abutments which are also available in prefabricated or customized form and can be prepared in the dental laboratory either by the technician or by utilizing computer aided design/computer aided manufacturing (CAD/CAM) systems. Often, prefabricated form do not provide refined morphologic enhancement of dental implant esthetics that in some clinically challenging cases require quite reduction of the abutment wall for esthetically favorable outcomes. There is rare study which investigated the effect of clinical abutment grinding procedures on the resistance of zirconia abutments by means of using rotary instruments.

Adatia *et al*.[9] concluded that margin preparation with irrigation up to 1.0 mm did not adversely affect the fracture strength of abutment assemblies and Att *et al*.[10] studied the effect of high speed grinding procedures which concluded that zirconia reduction up to wall thickness of 0.8 mm showed a favorable resistance to fracture. Both studies showed favorable fracture resistance after clinical reduction of zirconia abutments but the reported studies did not fully provide about this information whether a smaller wall thickness of zirconia abutments will lead to a detrimental effect on the stability of the abutment. So there is a need to define a minimal wall thickness that guarantees long-term stability without the effect of chair side modification procedures.

On the other hand, numerous researches about ceramic abutments had been reported, there were no reports about using resin-based materials as an esthetic abutment substitute. It is well known that resin composites have been used as an effective replacement of tooth structure for a long time though it was not considered as an implant substitute because of its relatively low mechanical strengths compared to ceramics like zirconia.

But their mechanical strengths had been quite improved with the development of various filler contents and linking methods including manufacturing systems as well. In company with these developments, a new resin composite block (Lava Ultimate CAD/CAM Restorative 3M ESPE Dental Products, St. Paul, MN, USA) has been proposed as substitutes of tooth - based fixed prosthesis including implant crowns. According to the manufacturers, Lava Ultimate is another new material for CAD/CAM technique. As introduced by its manufacturer, this material is called Resin Nano Ceramic (RNC) that is composed of approximately 80% nano ceramic filler (silica and zirconia) and 20% resin matrix.

From the view of dental materials, this material is one kind of zirconia reinforced resin composite, which is supposed to combine the properties of composite and ceramic. Like a glass ceramic, the material has excellent polish retention for lasting esthetics. Different from ceramic, the material is not brittle and shows favorable linking with the resin, easy shade matching, easy milling procedure without firing, higher fracture toughness and flexural strength than glass ceramics and composites. Due to its recent introduction to the market, few studies have been presented about its properties.[11]

It was, therefore, of interest to study whether this material could tolerate the occlusal strength as a dental implant abutment.

The aim of this investigation was to determine the minimal wall thickness of zirconia abutment that can withstand physiologic occlusal forces and explore the possibility of the resin-based materials as esthetic implant abutment alternatives as well.

Materials and Methods

Seventy implant abutments and fixtures (TiU, Nobel Biocare Inc., Zürich-Flughafen, Switzerland) with a diameter of 4 mm external hex were used in this study. The implant abutments were divided into 7 groups of 10 specimens each. Implant abutments of 0.5 mm Ti abutment wall were used as a control group (Ti-05), whereas abutments of zirconia (Lava Zirconia 3M ESPE, Seefeld, Germany) and resin nano ceramic abutments (Lava Ultimate CAD/CAM Restorative 3M ESPE Dental Products, St. Paul, MN, USA) (Zir-0.5, Zir-0.8, Zir-1.0, RNC-0.5, RNC-0.8, RNC-1.0) were prepared with different wall thicknesses. Group Zir-0.5 received zirconia abutments with a wall thickness of 0.5 mm by CAD/CAM. Group Zir-08 and Zir-1.0 received zirconia abutments with a wall thickness of 0.8 mm and 1.0 mm each. Group RNC-0.5, RNC-0.8, and RNC-1.0 were also prepared resin nano abutments with a wall thickness of 0.5 mm, 0.8 mm, 1.0 mm respectively by CAD/CAM technology.

Regardless of the wall thickness, the abutments of all groups had standard dimensions with a total height 10 mm. The shape of the abutment was cylinder with parallel walls. The internal dimension of the abutment was 3.6 mm and the top of the abutment was flat. The abutments representing each group (0.5, 0.8, 1.0 mm wall thickness) were fabricated according to the above mentioned thicknesses using a light-cured resin (Visio-FORM, 3M ESPE, Seefeld, Germany). The dimensions of the abutments were controlled using a precise thickness-measuring device (Digitmatic Micrometer, Mitsutoyo, Hamamatsu, Japan). Then, the representing sample abutments were scanned using a mechanical scanner (Lava Scan ST Design System, Seefeld, Germany) that operates by surface detection. After that, the zirconia abutments underwent milling and sintering through Lava CAD/CAM system. In case of resin nano ceramic abutments, the same representing samples were scanned and Lava Ultimate blocks were milled via the same CAD/CAM process.

The head of the milled abutment is then bonded to the titanium link (OUR-H & DER-H, Osung MND Co., Ltd., Seoul, Korea) interface with bonding material (Nimetic Cem, 3M Deutschland GmbH, Leipzig, Germany) by finger pressure. Specimen preparation and testing were performed by the same operator and completed in random sequence to avoid potential errors.

After delivery, all abutments were connected on the implant fixtures using titanium screws and tightened according to the manufacture's recommendation (35 Ncm) using the torque control system (TorqueTite, Nobel Biocare AB, Zürich-Flughafen, Switzerland). After 5 minutes, the above mentioned procedure was repeated to ensure proper tightening of the implant-abutment component.

All the specimens of each group were exposed to thermo-cycling device to simulate 1 year of clinical function. To simulate aging, the specimens underwent 10,000 cycles of thermo-cycling (KR/DTRC-640, JEIO TECH, Seoul, Korea) between two water baths; 5°C and 55°C for 30 seconds each, with an intermediate pause of 15 seconds.

For the final placement, the implants were fixed with a custom made steel universal chuck which can withstand 1,000 kg weight. Afterward, they were loaded compressively with a universal testing machine (Instron, Canton, MA, USA) with force application at an angle of 30° to the loading axis (Fig. 1). The testing angle was chosen as it represents mechanical loading conditions in the maxillary anterior areas where the esthetic abutments are considered.[8,12,13] A thin layer of tin foil was placed on the surface of the piston to prevent surface damage. And the abutments were loaded at the upper part of the specimen until the abutment failures occurred. The crosshead speed was 1 mm/ min and the applied force was graphically recorded on an x-t recorder (Instron Series IX version: 8.07.00, Canton, MA, USA). Fracture of the abutment was accompanied by an audible pop and failure was also recognized by a deviation from graphic linearity. The fracture mode of the abutments was also evaluated visually.

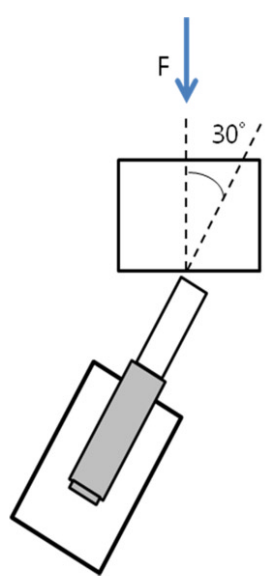

Fig. 1. Loading of the abutment with a universal testing machine. 30° degree angle was maintained.

The obtained data was expressed by mean and standard deviation. The distribution of strength was satisfied with normality assumption (result of the Shapiro-Wilk's test, $P > .05$) and a parametric method one-way analysis of variance (ANOVA) was used. If the global test revealed significant difference, the Tamhane post-hoc comparison method was applied in comparing each pair as the assumption of equal variances was not accepted (result of the Levene's test, $P < .001$). Also a two-way ANOVA was performed to assess whether there is an interaction effect between material and thickness. The statistical software SPSS 12.0 (SPSS Inc., Chicago, IL, USA) was used and a type one error rate $P > .05$ was applied to determine significance of a result.

Results

The final loads at fracture / distortion of all groups are shown in Table 1 and Fig. 2. During the test, two screw loosening were found in group Ti-0.5 and Zir-0.8 which revealed no statistically significant differences.

Among all the experimental groups, Zir-10 showed the highest mean strength 2,476.3 ± 342.0 N and Ti-0.5 and Zir-0.8 group were followed. All the strengths of Ti and Zir groups were higher than 500 N. The strengths of RNC groups were significantly lower compared to other two materials (RNC-1.0 427.5 ± 72.1, RNC-0.8 297.9 ± 41.2) and the strengths of all the test groups decreased as the thickness decreases ($P < .01$). And the RNC-0.5 (127.4 ± 35.3 N) abutments were weaker than all other groups ($P < .05$). The strengths of RNC-0.8 and RNC-1.0 were higher than 290 N.

Results of the two-way ANOVA showed significant interaction effect between materials and thicknesses ($P < .001$): the slope of strength according to wall thickness was significantly higher in Zir groups than RNC groups. Zir groups showed higher mean fracture strength than any resin groups ($P < .001$).

Table 1. Fracture/distortion strength of all tested groups (unit: N)

Group	Ti-0.5	Zir-0.5	Zir-0.8	Zir-1.0	RNC-0.5	RNC-0.8	RNC-1.0
Mean	1,041.8	631.4	1,518.1	2,476.3	127.4	297.9	427.1
SD	237.2	149	347.9	342	35.3	41.2	72.5

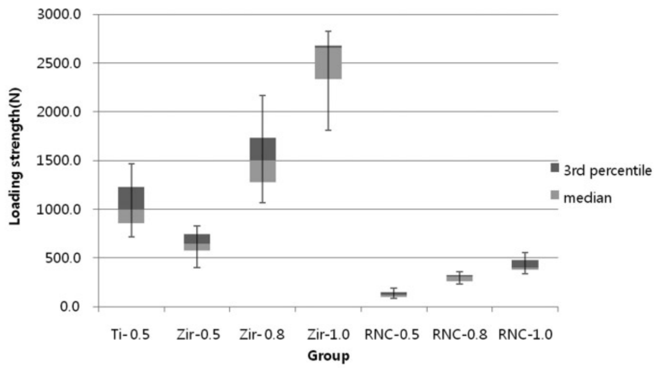

Fig. 2. Box plots of the results after the load-fracture test in N after thermocycling (n=10). Zir-1.0 group showed the highest mean strength and RNC-0.5 group showed the lowest mean strength among the test groups.

The failure modes were also observed. In the control group (Ti-0.5), failure occurred through the bending of the junction of implant-abutment connection in all samples which showed implant neck distortion. In test groups, all specimens showed abutment fracture before screw bending or fracture. The failure mode of the abutments in test groups showed the homogeneous manner; the total destruction of the abutment body with crack lines. No titanium link distortion was found.

Discussion

The main finding of this study was that all the zirconia abutments tested including 0.5 mm wall thickness have the potential to withstand the physiologic occlusal forces in anterior and posterior regions of oral cavity.

On investigating the fracture strength of different implant abutments, maximum biting forces should be considered. A large number of researches have been focused on the biting forces during human mastication.[14-16] And as well known, maximum bite forces vary according to the region of oral cavity. While the greatest bite forces are found in posterior regions especially in the first molar area, one- third or one-fourth of that maximum force is found in the anterior area. Some studies reported that the maximum force levels vary from 216 to 847 N and smaller force levels were reported in anterior area varying from 108 to 299 N.[14-16] The zirconia abutments investigated in this study exhibited mean fracture strengths of 631.4 at 0.5 mm wall thickness and 1,518.1 and 2,476.3 at 0.8 mm and 1mm wall thickness respectively which all exceeds above mentioned posterior maximum bite force.

In case of resin abutments, 0.5 mm wall thickness showed mean strength level of 127.4 N which represents unfavorable results even in the anterior area but 0.8 mm and 1.0 mm wall thicknesses revealed strength level of 297.9 N and 427.1 N, which exceed the average strength in anterior region.[15,17]

The test method used in this study was static loading, so cyclic loading with fatigue might yield different results. The lowest mean strength of zirconia 0.5 mm wall thickness in this study was 631.4 N which is higher than results of previous investigations.[18,19] Data on the fracture stability of zirconia abutments are difficult to compare between studies because of different study designs. However, previous researches have shown that the zirconia abutment was resistant enough for normal bite force.[18,19] In an *in vitro* study, unprepared titanium-reinforced zirconia showed median fracture load of 294 N and Ti control groups 324 N respectively, after fatigue and static loadings.[18] The conclusion of that study was that titanium-reinforced zirconia abutment performed almost the same manner to titanium abutment, so it can be recommended as an aesthetic substitute for single implant abutment in anterior region.

Currently zirconia implant abutments are designed and supplied with different types of implant-abutment connections. The external and internal connection of zirconia abutments can be accomplished either by the abutment itself (entire ceramic one-piece) or by means of secondary components (two-piece). One-piece abutments are made entirely of ceramic, whereas for two-piece abutments, the internal connecting parts are made by titanium insert or separate titanium link.

The influence of the type of connection on the stability of implant- zirconia abutment complex has been studied by Sailer *et al*.[20] who concluded that two-piece zirconia abutments with a secondary coupling abutment or metallic insert exhibited significantly higher bending moments than one-piece abutments. Another studies reported that abutment fractures occurred at the internal inserting part of the zirconia abutment after static fracture loading.[9,21] For this reason the specimens used in this study were designed as externally connected abutments with connecting titanium link to exclude the possibility of connecting part fracture of one-piece internal type.

Before the loading test, the whole specimens underwent thermocycling to simulate artificial aging. Although there are still many controversies about exact temperatures and dwelling cycles, no reports have suggested about the necessary number of thermo-cycles to simulate the use-time of a material *in vivo*. Therefore this study used the most commonly used temperatures 5°C - 55°C and 10,000 cycles to represent around a year of service in the mouth.[22]

Preparation of specimen and test set-up was basically performed according to the ISO 14801:2007 protocol. This investigation did not include a full veneer crown in the specimens. One study comparing the effect of adhesively cemented all-ceramic crowns of zirconia abutments concluded that ceramic restoration did not influence the bending moment of abutments in any of the test groups.[20] Another study with ceramic crowns over zirconia abutments had found the zirconia abutment failed in 40% of the specimens prior to either the all-ceramic crown fracturing or the screw component distortion.[8] An assumption that a crown may act as a stress-shield that allows a larger load to be applied before noticing any abutment fracture was extrapolated by the authors. In this study all the tested abutments were restored with neither metal crowns nor all-ceramic crowns which allowed not to obscure the cause of failure, that is, abutment related or crown related.[10] Also this type of experiment design was already used in other studies.[9,16,21] It might be needed some new kind of loading protocol or abutment design to ensure not only even distribution of the occlusal force but also force transfer without stress shield .

Generally, the clinical application of prefabricated zirconia abutments may need some kind of modifications or grinding procedures. It should be considered that the mechanical resistance of prepared ones might be different from that of unprepared ones. It is well known that zirconia material is highly susceptible to surface modifications and improper handling techniques.[23] Although some former studies showed that the prepared zirconia abutments did not yield statistically significant difference compared with unprepared ones, the current literatures does not provide exact information about this issue.[9,10] Hence there is still a need of guideline for the preparation of zirconia abutments as well as the minimal wall thickness of abutment that guarantees long-term stability. In this study, the smallest wall thickness of 0.5 mm showed mean fracture strength of 631.4 N which could tolerate posterior bite force of 500 N.

A few of ceramic abutments has been proposed as means of substitute of titanium abutments before the introduction of yttrium-stabilized zirconium dioxide (Y-TZP) abutments. However, there are no published clinical trials using resin materials as an implant abutment. The resin blocks used in this study are resin nano ceramic CAD-CAM materials introduced as a substitute for ceramics for inlays, onlays, crowns, and implant crowns by the manufacturer. It was produced as a new kind of composite product with 80% nano ceramic (silica and zirconia) fillers and 20% of resin matrix which underwent heat curing process. As this material contains resin matrix, it is beneficial in tensile strength than ceramic which has mechanical shortcoming of brittleness.

Although there are no reports published about this material as an implant abutment, it has shown favorable fracture resistances in this study at the wall thickness more than 0.8 mm. As well known, to succeed as a dental implant abutment, in many aspects, not only the mechanical strengths like fracture strength but also the bio-physiological compatibility including subgingival area should be proved. Additional further studies about resistance to persistent stress using cyclic loading and screw loosening due to resin nano ceramic material will be needed. And longitudinal clinical evaluations including fracture and discoloration etc. will be also necessary. Although the manufacturer reported comparable biocompatibility and mechanical strengths, more *in-vitro* studies about this material would be needed before any clinical appplication.

Conclusion

Within the limitations of this study, all the tested zirconia abutments have the potential to withstand the physiologic occlusal forces in anterior and posterior regions. In resin nano ceramic abutments, wall thickness more than 0.8 mm showed the possibility to withstand the occlusal forces in anterior regions. As the results of this study cannot be generalized to other implant system, further studies are needed to verify the minimal wall thickness of implant abutments.

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지르코니아와 레진나노세라믹 임플란트 지대주의 두께에 따른 열순환 후 파절저항

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목적: 이 연구의 목적은 심미적인 임플란트 지대주의 종류와 두께에 따른 파절 강도를 측정하여 구강 내 저작압에 견디는 최소한의 두께를 평가하기 위함이다.
재료 및 방법: 대조군으로 0.5 mm 두께의 티타늄 임플란트 지대주를(Ti-0.5), 실험군으로 지르코니아 임플란트와 레진 나노 세라믹 지대주를 사용하여 각각 0.5 mm, 0.8 mm, 1.0 mm 두께로 각 그룹에 10개씩 총 70개의 시편을 제작하였다(그룹Zir-0.5, Zir-0.8, Zir-1.0, RNC-0.5, RNC-0.8, RNC-1.0). 모든 시편은 파절 실험 이전에 열순환을 시행하여 구강 내에서의 사용을 재현한 후, universal testing machine을 이용하여 각 시편의 파절 강도를 측정하여 평균값을 측정하였다. 그룹들의 평균 파절 값을 측정하였으며 이원분산분석을 이용하여 통계학적으로 분석하였다.
결과: Zir-1.0군이 가장 높은 파절 강도 2,476.3 ± 342.0 N를 보였으며 뒤를 이어 Zir-0.8 (1,518 ± 347.9 N), Ti-0.5 (1,041.8 ± 237.2 N), Zir-0.5 (631.4 ± 149.0 N), 의 순이었다. RNC 그룹의 경우에 Ti와 Zir 그룹에 비교하여 유의하게 낮은 파절 강도값을 나타내었으며(RNC-1.0 427.5 ± 72.1, RNC-0.8 297.9 ± 41.2), 모든 실험군에서 지대주 두께가 감소할수록 파절 강도 값도 유의하게 감소했다($P < .01$). RNC-0.5 (127.4 ± 35.3 N) 그룹은 다른 모든 군에 비해 유의하게 낮은 값을 보였다($P < .05$).
결론: 이번 실험에서 사용된 모든 두께의 지르코니아 지대주는 전치부와 구치부의 교합압을 견딜 수 있는 정도의 파절 강도를 보여주었다. 레진 나노 세라믹 지대주의 경우 0.8 mm 두께 이상에서 전치부의 교합압을 견딜 수 있는 가능성을 보여주었다. *(대한치과보철학회지 2017;55:144-50)*

주요단어: 나노세라믹; 지대주; 힘저항능; 지르코니아; 파절

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