Influences of Screw Access Hole and Mechanical Cycling on the Fracture Load of Implant-Supported Crowns

Luciano Rosa, DDS, MS
Márcia Borba, DDS, PhD
Fernando Mallmann, DDS, MS
Fernando Fornari, PhD
Alvaro Della Bona, DDS, MMedSci, PhD

Postgraduation Program in Dentistry, Dental School, University of Passo Fundo (UPF), Passo Fundo, Brazil.

Purpose: To assess the influence of a screw access hole (SAH) and mechanical cycling on the fracture load of implant-supported crowns (ISCs) manufactured with screw-retained (s) or cement-retained (c) abutments with either metal (M) or zirconia (Z) infrastructure. Materials and Methods: Six groups of restorations were made based on type of infrastructure (M or Z), fixation (s or c), and whether they underwent aging (a) with mechanical cycling: Zc, Zs, Zsa, Mc, Ms, and Msa. All ISCs were porcelain veneered and tested for compression failure in distilled water (37°C) using a universal testing machine. ISCs from groups Zsa and Msa were mechanically cycled (106 cycles; 2 Hz, 100 N) in distilled water before compressive testing. Fractographic principles were followed to assess the fracture surfaces. The fracture load data were statistically analyzed using one-way analysis of variance and Tukey test (α = .05). The relationships between experimental group and failure mode were analyzed using chi-square test (α = .05). Results: Regardless of the infrastructure material, cement-retained ISCs (Zc and Mc) showed higher fracture load values than screw-retained ISCs (Zs, Zsa, Ms, and Msa) (P < .001), which were statistically similar to each other (P > .05). Aging had no effect on the fracture load of ISCs. There was a significant relationship between failure mode and experimental group (P < .001). Catastrophic fractures were found only in Zc and Zs. All metal-based ISCs failed from chipping reaching the metal infrastructure. Conclusion: Cement-retained ISCs showed higher fracture resistance than screw-retained prostheses. No catastrophic failures were found for metal-based ISCs. Aging did not affect the fracture load, but did affect the failure mode of ISCs. Int J Prosthodont 2019;32:423–429. doi: 10.11607/ijp.6286

Dental implants are an effective rehabilitation treatment option mostly because of the clinical and biologic success of osseointegration.1 Thus, implant-supported crowns (ISCs) are a therapeutic alternative for replacing lost teeth.2 Yet, the association between thin gingival tissue and metal-ceramic restorations has offered an esthetic challenge to the rehabilitation of anterior teeth.3 All-ceramic restorations may offer a better resolution due to their optical properties—mainly color and translucency—avoiding the grayish appearance resulting from most metal-ceramic restorations.4

Computer-aided design/computer-assisted manufactured (CAD/CAM), yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramics are the most popular infrastructure material for all-ceramic restorations. Y-TZP presents better mechanical behavior than other dental ceramics because of its toughening mechanism, transformation toughening.5 When subjected to external stimuli (eg, bite force, bur abrasion, etc), the tetragonal phase of zirconia transforms into the monocyclic phase, resulting in a 3 to 5 vol% increase that produces compressive stresses and nucleation of microcracks (microcrack toughening), preventing crack propagation and structural...
failure. Thus, Y-TZP ceramics may be used to produce implant-supported abutments, monolithic restorations, and infrastructures.

A prosthetic treatment is chosen based on the analysis of several factors related to the clinical performance of the restoration and to patient expectations, including reversibility, passivity, retention, occlusion, esthetics, and financial cost. Such factors should be considered when selecting the infrastructure material and the type of prosthesis retention (screw or cement).

The influence of implant-supported prosthesis retention on the longevity of oral rehabilitation has been reported. Cement-retained prostheses are influenced by several factors, such as surface area and preparation angles; abutment height; surface roughness of the abutment and the inner part of the crown; mechanical interlocking; and cement characteristics. Nevertheless, the principle of reversibility, which allows removing and reinserting the restoration without damaging it, is considered by many authors to be one of the advantages of screw-retained compared to cement-retained prostheses. However, the occlusal discontinuity present in screw-retained prostheses reduces the strength of the restorative material. Such occlusal discontinuity of the ceramic may cause chipping and catastrophic fractures. Studies have shown that oral service causes degradation of physical and mechanical properties of ceramic restorations. The effect of cyclic loading on fatigue behavior and subcritical crack growth of ceramics may be determined by tests that simulate the clinical conditions. An artificial oral environment may be simulated by controlling humidity and temperature. For clinical significance, a minimum of 106 cycles should be performed, which corresponds to approximately 1 year of oral service.

The present study evaluated the influence of a screw access hole (SAH) and mechanical cycling (aging) on the maximum fracture load ($L_f$) of ISCs manufactured with the same design for screw-retained and cement-retained abutments with either metal or zirconia infrastructure, testing the hypotheses that (1) the SAH affects the $L_f$ values and the failure mode of ISCs; (2) the type of infrastructure material affects the fracture behavior of ISCs; and (3) aging reduces the maximum fracture load of ISCs and changes the failure modes.

**MATERIALS AND METHODS**

Six experimental conditions were evaluated, grouped according to infrastructure material (zirconia [Z] or metal [M]), type of fixation (cement retained [c] or screw retained [s]), and the presence of previous mechanical cycling (a): Zc, Zs, Zsa, Mc, Ms, and Msa. Twelve crowns each were produced for groups Zc, Zs, Mc, and Ms, and 10 crowns each were produced for the groups subjected to mechanical cycling, Zsa and Msa. Thus, a total of 68 ISCs were fabricated for the six experimental groups.

Twenty-four supporting bases (diameter: 25.4 mm; height: 20 mm) were fabricated by slicing a rod of continuous glass-woven fabric impregnated with epoxy resin (G10, NEMA Grade G-10; Accurate Plastics) that had an elastic modulus similar to human bone. A central hole (diameter: 4.3 mm; height: 12.5 mm) was drilled (Twist Drill; Conexao Sistemas Protese) into the supporting bases. Autopolymerizing epoxy resin (FiberGlass; Fiberglass) was applied on dental implants (4 × 11.5 mm; AR morse NP; Conexao Sistemas Protese) and inserted into the central hole of each supporting base, ensuring that the implant was placed 1 mm below the surface of the base.

Abutments (height: 3.95 mm; occlusal diameter: 4.5 mm; Speed; Conexao Sistemas Protese) with a total occlusal convergence (TOC) of 8 degrees were customized to allow for both cement-retained and screw-retained ISCs (Fig 1). The abutments were connected to the implants (torque: 20 Ncm) following the manufacturer’s recommendations.

The abutment/base structure was scanned (DS-6000; Tecnodrill) to produce the CAD infrastructure project, configured as a single crown (standard premolar with plain occlusal surface) with a minimum wall thickness of 0.5 mm. As previously described, the infrastructure wall thickness was made to gradually compensate for the TOC, producing parallel external axial walls. Additionally, the infrastructures were designed to allow for a cement layer of 20 µm (for the cement-retained ISC) or a 3-mm diameter SAH (for the screw-retained ISC) to fit the manufacturer’s recommended screw (Esteticone/Standard; Conexao Sistemas Protese). All crowns had a mesial-distal width of 7 mm, a TOC of 8 degrees, and a final thickness of 1.2 mm for the axial and occlusal walls.

The zirconia (Upcera; Schenzhen Upcera) infrastructures were fabricated (DM-5; Tecnodrill) and sintered (ME1600/1; Fortelab Industria Fornos Eletricos) at 1,480°C, according to the manufacturer’s recommendations. An identical CAD project was used to make the metal infrastructures. CAD/CAM wax blocks were milled (DM-5; Tecnodrill) to obtain wax patterns, which were invested (Bellavest SH and BegoSol HE; BEGO). Metal (Vironia light; BEGO) infrastructures were obtained using the lost-wax casting process. Twenty-two crowns with an occlusal opening (screw-retained) and 12 crowns without an occlusal opening (cement-retained) were obtained for each type of infrastructure material (metal and zirconia).

Zirconia and metal infrastructures were veneered with compatible porcelains (VM9 and VM13; Vita Zahnfabrik). A silicone mold (Zetalabor; Labordental) was made and used to ensure a final porcelain thickness of 1.2 mm for the occlusal and axial walls. The porcelain
sintering cycles (Fortelab furnace ME1600/1) followed the manufacturer's recommendations.18

The cement-retained (metal and zirconia) ISCs had their intaglio surfaces silica coated (Rocatec Soft; 3M ESPE) at 280-kPa pressure18 using an airborne-particle-abrasion device (Rocatector; 3M ESPE). The resin cement system (RelyX U200 Clicker; 3M ESPE) was manipulated per the manufacturer's recommendations and applied to the intaglio surface of the ISCs, which were cemented onto the implant abutment under a constant load of 7.4 N for 5 minutes. Excess cement was removed.

The screw-retained (metal and zirconia) ISCs were attached using the manufacturer's recommended screw (Esteticone/Stardard; Conexao Sistemas Protese) with a 10-Ncm torque (Conexao Sistemas Protese). The screw head was covered with a 100% polytetrafluoroethylene-based resin filling material. A 10% hydrofluoric acid (HF) solution was used to etch (60 seconds) the porcelain surface of the SAH. The etched surface was spray washed and dried, silanated (Clearfil ceramic primer; Kuraray Noritake Dental), and allowed to dry for 5 minutes. The treated surface was completely dried with oil-free air. The adhesive system (Adper Single Bond 2; 3M ESPE) was applied on the treated porcelain surface and light activated (Optilight LD Max; Gnatus Equipamentos Médico-Odontológicos) for 20 seconds. A composite resin (Filtek Z350; 3M ESPE), light activated (Optilight LD Max; Gnatus Equipamentos Médico-Odontológicos) for 20 seconds, was used to seal the SAH.18

The ISCs from groups Msa and Zsa were mechanically cycled (Biocycle, BioPDI) in 37°C distilled water using the following parameters: 106 cycles, load of 100 N, frequency of 2 Hz. Cyclic load was applied using a stainless steel rounded-point piston (diameter: 6 mm) onto the center of the occlusal surface of the ISCs.18

Initially, the 24 bases were used to test 44 screw-retained crowns (12 from Zs, 10 from Zsa, 12 from Ms, and 10 from Msa). Then, these 24 bases were used for cementing the crowns of the cement-retained groups (12 from Zc and 12 from Mc).
All ISCs were tested under compression in distilled water (37°C). The load was applied onto the center of the occlusal surface of the crowns using a piston identical to that used for cyclic loading. The piston was attached to a universal testing machine (EMIC DL 2000; EMIC-Instron) set for a crosshead speed of 0.5 mm/minute until failure or until a significant drop in the load curve associated with an evident crack sound.\(^1^8\)

The maximum \(L_f\) values were statistically analyzed using one-way analysis of variance (ANOVA) and Tukey test (\(\alpha = .05\)).

Fractured surfaces were evaluated under a stereomicroscope (Stemi 2000-C; Carl Zeiss) to record the most complex failure type (catastrophic or porcelain chipping) and fracture origin. For the purpose of this work, a fracture of the crown involving the whole infrastructure (ie, crown broken into two main pieces) that was considered clinically nonreparable was defined as a catastrophic failure, and fractures of the porcelain veneer with or without infrastructure involvement that were considered clinically reparable failures were defined as chippings.\(^4^,5\)

Representative fractured ISCs were coated with gold palladium and further examined under scanning electron microscopy (SEM) to confirm the crack origin. Chi-square test was used to evaluate the association between study group and failure mode (\(\alpha = .05\)).

**RESULTS**

Statistical analysis showed that the type of fixation affected the \(L_f\) values. The cement-retained groups (Zc and Mc) presented the greatest mean \(L_f\) values. The screw-retained groups (Zs, Zsa, Ms, and Msa) presented lower \(L_f\) values, which were similar among all four groups. Thus, type of infrastructure material and mechanical aging did not affect the \(L_f\) values (Table 1).

A summary of the failure modes is shown in Table 1. There was a significant relationship between failure mode (catastrophic, chipping with or without infrastructure involvement) and experimental groups. After aging, all Zsa crowns failed due to porcelain chipping (Figs 2a and 2b). Only the zirconia-based infrastructure crowns (Zs and Zc) showed catastrophic fractures (Fig 2c); that is, nine Zc crowns (75%) and one Zs crown (8%) failed catastrophically, with crack origins similar to those found in a previous report.\(^1^8\) All ISCs with metal...
infrastructure (Ms, Mc, Msa) failed due to chipping with infrastructure exposure (Figs 3 and 4).

All screw-retained crowns with Y-TZP infrastructure (Zs and Zsa) had cervical margin involvement in the fracture (Figs 2a and 2b). Nonetheless, the screw access area was compromised in 33% of the Zs group and in 40% of the Zsa group. For the Zc group, most failures were catastrophic and involved both cervical and occlusal areas (Fig 2c). For the screw-retained ISCs with metal infrastructure (Ms and Msa), failures involving the loading area increased from 42% to 100% after aging. All failures in cemented ISCs (Zc and Mc) involved the occlusal surface.

**DISCUSSION**

The SAH (ie, type of fixation) affected the Lf and failure mode of ISCs, confirming the first study hypothesis. The presence of an occlusal opening in screw-retained crowns significantly reduced the fracture load values regardless of the infrastructure material used, which is in agreement with a previous study. Yet, the greatest Lf values of cement-retained crowns, mainly the Zc ISCs, were also associated with the greatest percentage of catastrophic fractures, which are nonreparable failures.

---

**Fig 3** (a) Compression-loaded and aged screw-retained metal crown (Msa) showing porcelain chipping reaching the metal infrastructure (delamination). (b) Porcelain chip showing the opaque porcelain layer detached from the metal surface; fracture origin is within the white circle (×10). (c) Scanning electron microscopy image of the fracture origin located at the cervical margin in the metal-opaque interface (magnification: ×320). A complete map of this porcelain chip is presented in Fig 4.

---

**Fig 4** Mapping of the fracture shown in Fig 3. Scanning electron photomicrographs of the porcelain chipping (central image) from an aged screw-retained metal crown (Msa). The fracture origin, located at the cervical margin at the metal-opaque interface, is circled in black and enlarged in the lower left image. The black squares are magnified to the left and right of the central image and show wake hackles (white asterisks) in the porcelain (P) layer and the direction of crack propagation (white arrows). Several cracks are shown in the screw access hole (SAH) area, but they do not play a relevant role in the fracture event (delamination). O = opaque layer (better seen on Fig 3b).
A similar study using three-unit implant-supported fixed dental prostheses (ISFDPs) with SAH showed lower Lf values regardless of the framework type, agreeing with the present study. \(^1\) Similarly, another study using five-unit metal-ceramic FDPs showed significant differences in fracture load values between cement- and screw-retained prostheses, concluding that the absence of SAH improved ceramic stability. \(^2\) Thus, the present study using ISCs is in agreement with previous reports using three-unit and five-unit ISFDPs, showing that the mechanical behavior of cement-retained prostheses is better than screw-retained prostheses. Yet, the clinician should be aware of the high incidence of residual cement and subsequent peri-implantitis in cement-retained ISCs. \(^3\) The removal of excess cement after cementation should be given high priority, as excess cement may lead to catastrophic biologic failure with much greater consequences than redoing a prosthesis.

On the other hand, a study assessing the effect of SAH on the fracture load of different types of ceramic crowns did not find any statistical difference between screw- and cement-retained crowns. The study showed that only the zirconia-based monolithic crowns showed higher fracture load values than the lithium disilicate or porcelain-veneered zirconia crowns. \(^8\)

The present study showed that the fracture load of ISCs with the same type of retention but different type of infrastructure material (zirconia or metal) were statistically similar, which agrees with the literature. \(^10,12,18\) However, all ISCs with metal infrastructure failed due to porcelain chipping, and catastrophic fractures were observed only in ISCs with zirconia infrastructure (Zs and Zc), which also showed porcelain chipping. Therefore, the second study hypothesis was partially confirmed. These fracture patterns are mostly associated with the mechanical properties of the infrastructure materials and the infrastructure-veneer interfacial bond strength.

Porcelain chipping occurred in all (100%) aged crowns (Ms and Zsa), which was not much different from non-aged crowns (100% for Ms and 92% for Zs). That is, mechanical aging had no effect on the fracture loads and an insignificant effect on the mode of failure of ISCs (Table 1), rejecting the third study hypothesis. These findings agree with a study that showed no influence of 1-year simulation of masticatory cycle on the fracture load of ISFDPs. \(^17\) A study on fracture resistance and failure modes of zirconia-based crowns with different ceramic veneering after cyclic and static loading concluded that the veneering fabrication technique affects the fracture load of crowns with zirconia infrastructure and that the cohesive failure (chipping) of the veneering porcelain prevailed. \(^11,15\) Further, another study showed that 1-year simulation of mechanical aging affected the fracture load of three-unit fixed dental prostheses depending on the type of ceramic infrastructure, with Y-TZP infrastructure being more susceptible to degradation than other materials. \(^19\) Yet, clinical studies are not reporting such problems with zirconia infrastructure restorations. A 3-year follow-up study observing 19 crowns with zirconia infrastructure placed in severely destroyed anterior teeth showed a survival rate of 100%. \(^13\) Another clinical and retrospective study evaluated 102 anterior and posterior crowns for an average time of 20.9 months and reported no infrastructure fractures. \(^14\)

Considering that the mean masticatory force is 220 N in the posterior region \(^25\) and may reach 1,181 N with parafunctional habits, \(^26\) all ISCs evaluated in this in vitro study were able to resist the usual masticatory loads in the posterior region of the mouth. Thus, the results of the present study, which attempted to simulate intraoral service (cyclic loading in a humid environment), showed similar clinical behavior reported for the types of restorations assessed. \(^13,15\)

**CONCLUSIONS**

Within the limitations of this in vitro study, the following can be concluded: (1) the Lf was significantly higher for cement-retained ISCs than for screw-retained ISCs regardless of the infrastructure material; and (2) neither the infrastructure material (zirconia or metal) nor the aging protocol used in the study significantly affected the Lf of the evaluated ISCs. Yet, no catastrophic failures were found for metal-based ISCs.

**ACKNOWLEDGMENTS**

This study was partially supported by CNPq do Brazil grant #302587/2017-9. There are no conflicts of interest associated with this study.

**REFERENCES**


© 2019 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
Zirconia Abutments in the Anterior Region: A Systematic Review of Mechanical and Esthetic Outcomes

The success of single anterior implant-supported restorations relies on mechanical and esthetic outcomes. Titanium has been the most commonly used material for abutments, but zirconia is increasingly chosen for its appearance despite its unclear mechanical performance. Today, manufacturers market prefabricated computer-aided design/computer-assisted manufacturing (CAD/CAM) custom and zirconia abutments when compared to titanium, despite reservations concerning the risk of mechanical complications. Data are lacking concerning fracture resistance analysis. J Prosthodont 2018;27:651–658.


References:

Naveau A, Rignon-Bret C, Wulfman C. J Prosthodont 2019;121:775–781.e1. References: 44. Reprints: Claudine Wulfman, claudine.wulfman@parisdescartes.fr — Paolo Vigolo, Italy