Article published online: 2021-09-14

Hybrid Implant Abutments: A Literature Review

Azam Sadat Mostafavi[1] Hamid Mojtahedi[2] Afrooz Javanmard[3]

[1]Department of Prosthodontics and Dental Research Center, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
[2]Oral and Maxillofacial Surgery Department, Craniomaxillofacial Research Center, Tehran University of Medical Sciences, Tehran, Iran
[3]Department of Prosthodontics, Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Address for correspondence Afrooz Javanmard, DDS, Department of Prosthodontics, Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Velenjak, Daneshjoo Blvd., Tehran - 19857-17443, Iran (e-mail: afroozjavanmard.69@gmail.com).

Eur J Gen Dent 2021;10:106–115.

Abstract

Ceramic implant abutments are becoming increasingly popular due to the growing esthetic demands of patients. Two-piece ceramic abutments have the advantages of both ceramic and titanium abutments. This study aimed to review the published articles regarding hybrid abutments and their characteristics.

Published articles regarding two-piece abutments were retrieved by electronic search of PubMed, Embase, Scopus, Medline, and Google Scholar databases using certain keywords. Articles highly relevant to our topic of interest were selected and reviewed.

The presence of titanium inserts in hybrid abutments can overcome the brittleness of ceramic, increase the overall fracture resistance, prevent the implant connection wear, and provide better marginal fit compared with one-piece zirconia abutments. Hybrid abutments enable the fabrication of monolithic metal-free implant restorations with optimal esthetics. Furthermore, the risk of porcelain chipping, which is a common complication of implant restorations, is eliminated due to the monolithic structure of these restorations.

According to the available literature, hybrid implant abutments have shown promising results with regard to optimal esthetics in the rehabilitation of the esthetic zone. However, long-term clinical studies are required to assess the long-term durability of all-ceramic restorations supported by hybrid abutments.

Keywords
► dental abutment
► dental implant
► porcelain
► two-piece abutment

Introduction

Titanium implant abutments are widely used due to their optimal physical and mechanical properties, including high strength and biocompatibility. However, these abutments compromise the esthetic appearance of the final restoration due to their gray color, especially in patients with a thin mucosa.[1,2] Over time, the development in ceramics and computer-aided design and computer-aided manufacturing (CAD/CAM) systems, along with an increasing esthetic demand of patients, led to the fabrication of all-ceramic abutments that improved the esthetic outcome of treatments.[3,4]

High-strength ceramics, including zirconia, are now an optimal option for the fabrication of implant abutments. Customized zirconia abutments are fabricated in two forms, one-piece and two-piece abutments. One-piece zirconia abutments have several shortcomings. Evidence shows titanium abutments have a significantly better fit than zirconia abutments as ceramics cannot be machined as accurately as metals.[5] The mean gap size in the zirconia abutments is 3 to 7 times larger than that in the titanium abutments.[6] High rate of fracture is another drawback of one-part zirconia abutments, which either occurs at the implant–abutment connection or in the transmucosal part of the abutment.[2]

DOI https://doi.org/10.1055/s-0041-1735766
ISSN 2320-4753

Thieme Medical and Scientific Publishers Pvt. Ltd. A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

In contrast, significant differences in the physical properties of zirconia and titanium, especially, in terms of hardness and modulus of elasticity, can cause wear and damage to the internal components of the implant fixture.[7,8] Due to the aforementioned limitations, the idea of hybrid abutments was suggested. Hybrid abutments consist of a titanium insert, which is connected to a ceramic mesostructure using a resin cement; thus, these types of abutments have the advantages of both ceramic and titanium abutments, including improved esthetics, optimal biological response, and superior mechanical properties, with no adverse effects on the implant–abutment interface.[9] This study aimed to review the different characteristics of these abutments.

Materials and Methods

Databases including PubMed, Embase, Scopus, Medline, and Google Scholar were searched for articles on hybrid abutments. Studies regarding different characteristics of hybrid abutments were selected. The search keywords included "hybrid abutment," "customized ceramic abutment," and "two-piece ceramic abutment."

After reviewing the retrieved articles, the extracted data were categorized in the following order:

- Cement or screw-retained restorations.
- Material selection.
- Digital and conventional workflow.
- Bonding to titanium abutments.
- Effect on peri-implant soft tissue and bone.
- Mechanical properties.
- Mode of failure.

Cement or Screw-Retained Restoration?

Restorations supported by hybrid abutments can be cement-retained or screw-retained. Several advantages and disadvantages have been described for cement- and screw-retained restorations in the literature.[10-12] The main advantages of screw-retained over cement-retained restorations include retrievability, better tissue tolerance, and insignificant biological complications.[12-14] However, a higher rate of technical complications, including screw loosening and ceramic chipping, have been reported for this kind of restoration.[15] Because of an easier laboratory fabrication process, cement-retained restorations are more frequently used compared with screw-retained restorations. The main advantage of these restorations is esthetics due to the absence of a screw access opening.[10,13,14] Because of the small cement space that serves as a stress breaker, it is easier to achieve passivity.[16,17] The main disadvantage of cemented restoration is excess cement that can cause peri-implantitis.[18-20] To benefit from the advantages of both cement- and screw-retained restorations, the combination implant crown technique (screw-cemented-retained restorations) was proposed.[21,22]

Material Selection

Zirconia

Zirconia abutments exist in the form of prefabricated (stock) or CAD/CAM-customized abutments. Prefabricated abutments have drawbacks compared with customized abutments, including lower load-bearing capacity and limited ability for individualization.[23] CAD/CAM-customized abutments enable the fabrication of abutments with the desired shape and size, optimal finish line design and emergence profile according to the soft tissue position. Customized zirconia abutments are fabricated in two general forms: one-piece (monolithic) or two-piece (hybrid) zirconia abutments. One-piece zirconia abutments are fabricated as one-part components and are directly connected to the implant (►**Fig. 1**). The implant-abutment interface is fabricated out of semi-finished zirconia blanks during manufacturing and only the external geometry of the abutment is milled based on the clinical conditions. The strength of these abutments is significantly lower than that of two-piece abutments.[24,25] In addition, these abutments are less frequently applied due to the possibility of clinical complications as mentioned before. In contrast, the restorative vertical height and the implant connection design can affect the success of these abutments.[26] Hybrid abutments are made up of two components, a titanium insert and a transmucosal zirconia part, which are connected to the implant by the titanium insert (►**Fig. 2**). The titanium insert is prefabricated by the implant manufacturers and its accuracy is as high as titanium abutments. The ceramic mesostructure is customized by CAD/CAM technology based on the esthetic needs. Partially prefabricated mesoblocks are made of pre-sintered zirconia and have connection geometry for attachment to the titanium insert. The interface between the titanium base and zirconia abutment often contains an anti-rotation feature that prevents the rotation of abutment and helps in the correct bonding of two components.[27]

Precrystallized Lithium Disilicate

Introduction of pre-crystallized lithium disilicate blocks (IPS-Emax CAD), which have a perforation that provides an intimate fit with the titanium insert, enabled the fabrication of monolithic implant-supported restorations even with the chair-side CAD/CAM systems. The monolithic nature of restorations prevents some complications such as ceramic fracture

Fig. 1 One-piece zirconia abutments.[93,94]

Fig. 2 Two-piece (Hybrid) zirconia abutments. These abutments consist of two parts, a titanium insert and ceramic mesostructure.[95]

and chipping.[28] Lithium disilicate is the strongest and toughest glass-ceramic, with moderate flexural strength,[29] moderate fracture toughness,[30] and excellent translucency.[31] Lithium disilicate abutments can be used in the form of hybrid abutment with a separate crown (cement-retained restoration) or hybrid abutment-crown with the abutment and crown fabricated as one piece, which will then be bonded to the titanium insert (screw-retained restoration) (►**Fig. 3**).

Hybrid Ceramic Blocks

Polymer-infiltrated ceramic network material is a new category of materials with an interconnected dual network structure of ceramic and polymer (VITA ENAMIC, Vita Zahnfabrik).[32] This group of materials has the advantages of both ceramics (optimal durability and color stability) and composite resins (improved flexural properties and low abrasiveness).[33] Enamic by VITA is among these materials, which is composed of a pre-sintered feldspathic ceramic (86 wt% or 75 v%) reinforced by a polymer network (14 wt% or 25 v%).[33,34] The Enamic-perforated blocks used for the fabrication of monolithic screw-retained implant-supported restorations have an integrated connection, which is compatible with the titanium bases (►**Fig. 4**). Restorations fabricated using these materials do not require sintering or post-mill firing, which results in reduced fabrication duration.[35]

CAD/CAM Polymethyl Methacrylate Blocks

Polymethyl methacrylate blocks (Telio CAD and VITA CAD temp) are indicated for implant-supported, long-term provisional single restorations for the purpose of soft tissue management. These blocks are available with a connection geometry for attachment to a titanium insert.[36,37] (►**Fig. 4**).

Digital versus Conventional Workflow

Hybrid abutments may be produced in a digital or conventional workflow. In the conventional method, the abutment-crown is formed over the prefabricated titanium base with wax that will be transferred to lithium disilicate through the pressing technique (IPS e.max Press). The restoration should be tried in the oral cavity prior to bonding the hybrid abutment/crown to the titanium base due to the required correction. In the digital technique, a digital

Fig. 3 Lithium disilicate blank (IPS-Emax CAD, Ivoclar Vivadent) for single-unit restoration in two forms of hybrid abutment crown (right) or hybrid abutment with separate crown (left).[96]

Fig. 4 CAD/CAM blank based on hybrid ceramic (VITA ENAMIC, Vita Zahnfabrik) and PMMA (Telio CAD and VITA CAD temp).[97]

impression is made either from the oral cavity by a scan body/scan post or from the cast. The proper titanium insert is selected according to the implant system and then CAD/CAM software is intended to design and fabricate the abutment or abutment/crown.[27]

Bonding to Titanium Insert

The weak point of hybrid abutments is the adhesive connection between the titanium insert and ceramic mesostructure, which plays an important role in the long-term clinical success of restorations.[38] In the following, several factors that affect the retention force between these two components are discussed.

Surface Treatment

Surface treatment is considered for both ceramic and titanium insert surfaces. Several conditioning treatments for zirconia were suggested to obtain a strong bond between the zirconia and resin cement. Sandblasting with aluminum oxide particles (Al_2O_3) with different shapes and sizes (30 to 250 µ), pressure values, and time duration is the most common method to achieve this goal.[39] However, the effect of this method in increasing the surface roughness of zirconia is still a subject to debate.[40-45] Considering the shortcomings of sandblasting, some other surface treatments were suggested for zirconia, including tribochemical silica coating,[46] selective infiltration etching,[47] laser irradiation,[48] and nanostructured alumina coating.[49] Evidence shows that airborne-particle abrasion of zirconia and application of phosphate monomers such as dipentaerythritol penta-acrylate phosphate or 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) increase its bonding to resin cements.[50-53] Mechanical adhesion to lithium disilicate can be achieved by airborne-particle abrasion with 50 µ aluminum oxide particles or acid etching with hydrofluoric acid and application of a silane primer. Previous studies have demonstrated that hydrofluoric acid etching,[54-56] airborne-particle abrasion.[57] or both[58-60] increased the bond strength between lithium disilicate and resin cements. In general, hydrofluoric acid etching is the preferred method for roughening the surface and increasing the retention of lithium disilicate ceramics.[61-63] The effect of ceramic etching depends on the substrate constitution, surface topography, acid concentration, and duration of etching.[64] Several studies have assessed the effect of titanium surface treatments on its bond strength to different cements, and different surface roughening techniques, including airborne-particle abrasion, tribochemical silica coating systems, and hydrofluoric acid etching, have been suggested for this purpose.[65,66] However, the results of studies regarding the effect of airborne-particle abrasion on the bond strength of luting agents to the metal substructure are controversial.[67-70]

Cement Type

In hybrid abutments, resin cements are recommended to obtain a stable bond with high retention and good marginal accuracy due to a chemical bond to both titanium and ceramic components.[38] To ensure the passive fit in computer-milled zirconia prostheses, they are fabricated with minimal mechanical retention. Thus, the retention provided by the cement is more important.[71] Evidence shows that resin cements containing methacryloyloxydecyl dihydrogen phosphate (MDP) can form a long-term durable bond to the sandblasted surface of zirconium oxide ceramic.[46,72] However, adequate information regarding the retention of zirconia copings cemented on titanium inserts in two-part abutments is not available and there is no consensus on the effect of resin cement type on the retentive strength of the ceramic and metal components in two-piece abutments.[52,70] ►**Table 1** summarizes the results of available articles on the retentive strength in hybrid abutments.

Ti-Base Height

It has been reported that the abutment geometry, especially the degree of taper and height, are among the factors affecting the retention of implant-supported restorations.[73] Abbo et al showed that a 1-mm increase in titanium abutment height leads to higher resistance of zirconia copings to tensile forces.[74] In contrast, Cano-Batalla et al concluded that a 1-mm difference in the abutment height had no significant effect on restoration retention.[75] The majority of relevant studies have assessed the effect of abutment length on the retention of traditional titanium abutments; however, the condition of titanium inserts is different from that of stock abutments because titanium inserts have mechanical interlocking and a lower degree of taper. According to Silva et al, the length of the titanium base (4 vs. 2.5 mm) has no significant effect on the retention of zirconia suprastructure.[76] The retentive part of the titanium base should have a height of around 4 to 6 mm; although titanium bases with 3.5 mm height are also available in the market, they may not be able to provide sufficient retention for the restorations.[69]

Luting Gap

The cement space is one of the determinants of the retentive strength between the titanium and zirconia components in two-piece abutments.[52,77] Ebert et al showed that zirconia copings fabricated with a 30 µ luting gap had significantly higher retention than those with a 60 µ luting gap.[38] Mehl et al demonstrated that cement gap (60 vs. 100 µ) had a significant effect on the retention between titanium inserts and zirconia components.[52]

Surface Characteristics

Evidence shows higher retention values in titanium inserts than conventional titanium abutments.[78,79] It can be due to the surface geometry of titanium bases and the presence of mechanical interlocking on their surface, which could improve the retention of zirconia suprastructure.[69]

Effect on Peri-Implant Soft Tissue and Bone

The mucosal attachment formed around titanium or ceramic abutments is composed of two parts: junctional epithelium and connective tissue.[80] Mehl et al assessed the effect of hybrid abutments made of zirconia or lithium disilicate bonded to a titanium base by resin cement on peri-implant tissues. They revealed that the abutment material and the use of two-piece abutments with adhesive resin joint had no significant effect on bone loss and soft tissue anatomy except that the height of junctional epithelium was longer around one-piece titanium abutments compared with two-piece zirconia abutments.[81] Mehl et al, in another study, demonstrated that two-piece implant abutments with a machined surface led to better adhesion of host cells than abutments with a polished or rough surface. They found no significant difference in cell adhesion to zirconia and lithium disilicate discs with machined surfaces.[82] Both studies confirmed the biocompatibility of zirconia and lithium disilicate hybrid abutments bonded to titanium bases.

Mechanical Properties

Several studies have reported that the use of titanium base in ceramic abutments can overcome the brittleness of ceramic and provide ceramic abutments with better support and higher fracture resistance.[2–5,9,83] A recent systematic review showed that titanium inserts bonded to zirconia increased the overall fracture resistance, prevented the implant connection wear, and resulted in better marginal fit compared with one-piece zirconia abutments.[84] Elsayed et al concluded that hybrid ceramic abutments made of zirconia and lithium disilicate can tolerate heavier loads compared with the

Table 1 Studies related to bonding to titanium bases in two-piece abutments

Authors	Measurement methods	Materials	Conclusion
Von Maltzahn et al 2016[70]	Evaluated the retention force (by pull-off test) after simulated aging	Titanium base bonded to zirconia coping with two different resin cements (Panavia F2 and RelyX Unicem) pretreated with six surface modifications	1. No significant difference was found between the two cements 2. All adhesion surfaces should be pretreated by sandblasting and a phosphate-base primer
Geherk et al 2014[89]	Evaluated the bond strength (by pull-out test) after thermocycling	Titanium inserts bonded to zirconia coping with three different types of resin cements Surfaces were air-abraded with aluminum-oxide particles	1. No significant difference between the retention values of three cements was found 2. The use of resin cements in combination with air abrasion of the bonding surfaces of titanium and ceramic led to stable retention of hybrid abutment
Bankoğlu Güngör et al 2018[90]	Evaluated the tensile strength after thermomechanical aging	Custom zirconia abutment bonded to titanium inserts with three different resin cements	1. Resin cement type had an effect on the retentive strength of custom zirconia abutment bonded to titanium inserts
Mehl et al 2018[52]	Evaluated the tensile load after thermocycling	Zirconia copings bonded on titanium inserts in two-piece abutments with two luting spaces (60 and 100 μ) and three different resin cements. The bonding surfaces were air-abraded with aluminum-oxide particles	1. The type of resin cement used and luting space had a significant effect on tensile load of zirconia copings on titanium bases
Linkeviciene et al 2019[69]	Evaluated the tensile force after thermocycling	Zirconia copings bonded on titanium bases with three different resin cements with a luting gap size of 30 μ. Titanium bases were airborne-abraded with aluminum-oxide particles	1. Abrading the titanium bases with 50 μ aluminum oxide particles decreased the bond strength of the coping from the titanium base
Zenthöfer et al 2018[91]	Evaluated the debonding force (tensile force up to failure)	Zirconia coping cemented to titanium inserts using composite cement after sandblasting. Half of them luted after application of an additional bonding	1. Customized two-piece zirconia abutments are a promising prosthetic treatment option 2. All debonding forces for customized two-piece zirconia abutments exceeded ~600 N
Freifrau von Maltzhan et al 2019[92]	The retention forces with a pull-off test after thermal aging	zirconia and lithium disilicate ceramics copings were bonded on titanium inserts by seven surface modifications and three resin-based luting agents	1. No mechanical pretreatment of the titanium base resulted in the lowest retention. 2. Surface modifications and resin-based agents influence the retention of components of two-part abutments. 3. Lithium disilicate ceramic copings reached comparable results of retention to the typically used zirconia copings

physiologic loads applied to the anterior region (150–235 N). Therefore, they are suitable treatment options for single implant rehabilitation in the anterior region.[2] A few studies have investigated the mechanical properties of lithium disilicate as an implant abutment material. Nouh et al demonstrated that zirconia hybrid abutment fracture resistance was significantly higher than that of lithium disilicate. They also reported that the mean load required for the fracture of lithium disilicate restorations in both types of abutment-crown and abutment with a separate crown was higher than the maximum masticatory force reported for the premolar region (222–445 N). Therefore, these restorations can be successfully used in the clinical setting for rehabilitation of the premolar region.[85] Elsayed et al showed that hybrid abutments made of zirconia and lithium disilicate (both forms of hybrid abutment-crown and abutment with a separate crown) can tolerate 1,200,000 fatigue load cycles with no fracture in ceramic abutment or crown and no screw loosening. They concluded that hybrid abutments with a titanium base have a considerably higher fracture resistance than one-part ceramic abutments (> 900 N) but no significant difference was noted between the hybrid abutments applied.[5] The effect of restoration design (hybrid abutment-crown versus hybrid abutment with a separate crown) has been evaluated by some studies; these reported that hybrid abutment zirconia restorations with separate crowns had a higher fracture strength than zirconia hybrid abutment-crown but this difference was not significant. This finding can be explained by the fact that the hybrid abutment design with a separate crown can better distribute the stresses due to the presence of several interfaces. However, in lithium disilicate restorations, the hybrid abutment-crown group showed higher fracture strength than the hybrid abutment group with a separate crown. This difference was attributed to the higher strength of the material when fabricated as monolithic and one-piece, compared with the fabrication of a separate crown with minimal thickness.[85,86] ►**Table 2** summarizes the results of available articles on the mechanical behavior of two-piece abutments.

Mode of Failure

Application of a fragile material on natural teeth is not problematic due to the presence of periodontal ligament, while the same material may cause a range of mechanical complications, including fracture and chipping when applied as implant restorations.[87] Several studies investigated the mode of failure of the implant-supported restorations using hybrid abutments. Nouh et al, observed failure in both titanium base (bending and fracture) and ceramic suprastructure (fracture and adhesive failure).[85] Elsayed et al reported that the most common failure mode in one-piece zirconia abutments was a fracture at the abutment-implant connection slightly higher than the implant shoulder, while permanent plastic deformation of abutment screw and internal connection of titanium base or distortion of the labial platform of

Table 2 Studies related to mechanical behavior of two-piece abutments

Authors	Measurement methods	Materials	Conclusion
Elsayed et al 2017[2]	Evaluated the fracture strength and failure mode	Five different abutments: titanium, zirconia with and without metal inserts, lithium disilicate with metal inserts in two forms of combination abutment-crown and abutment with separate crown	1. Lithium disilicate abutments have the potential to withstand the physiological occlusal forces that occur in the anterior region 2. The fracture strength of lithium disilicate abutments is not influenced when they are used as a combination abutment-crown 3. Failure occurred as a result of deformation of the titanium inserts and screws while ceramic suprastructure remained intact
Elsayed et al 2017[5]	Evaluated the effect of fatigue loading on the fracture strength and failure mode	Five different abutments: titanium, zirconia with and without metal inserts, lithium disilicate with metal inserts in two forms of combination abutment-crown and abutment with separate crown	1. The use of titanium inserts enhances the strength of zirconia abutments 2. Hybrid abutment and hybrid-abutment crowns made of lithium disilicate show promising durability and strength after long-term dynamic loading
Guilherme et al 2016[4]	Evaluated the static failure load	Three tooth-colored implant custom abutment bonded to titanium inserts: zirconia, lithium disilicate, resin-based composite (Lava Ultimate)	1. Zirconia abutments demonstrate high maximum load capacity 2. Customized resin-based composite and lithium disilicate abutments showed no statistical differences
Roberts 2018[86]	Evaluated the fracture strength	Four groups of titanium-based lithium-disilicate and zirconia abutment crown	1. Lithium-disilicate hybrid abutment with separate crown had significantly higher fracture load than all other groups
Nou et al 2019[85]	Evaluated the fatigue resistance, fracture resistance and mode of failure (static loading after chewing simulation)	Posterior hybrid-abutment crown and hybrid abutment with separate crown with two materials: zirconia and lithium-disilicate	1. Zirconia and lithium-disilicate hybrid restorations with short titanium inserts failed in a considerable number during chewing simulation 2. Despite their high fracture resistance, the use in the posterior region should be considered critically

the implant was observed, with no fracture in the ceramic, in zirconia and lithium disilicate hybrid abutments with a titanium base.[2,5] Gehrke et al. demonstrated that the fracture of all-ceramic abutments always initiated in the ceramic part beneath the implant shoulder; however, the failure of the samples mainly occurred in the abutment screw in two-piece zirconia abutments, which is the weakest within the assembly and was in the form of bending and eventual fracture.[3] In addition, Rosentritt et al. reported the bending and fracture of abutment screws as the most common failure modes of hybrid abutments.[88] The comparison of three types of tooth-colored implant custom abutments under fatigue test revealed that the titanium insert broke in the zirconia group while brittle fracture occurred in the tooth-colored part of lithium disilicate and Lava Ultimate groups.[4]

Conclusion

In esthetically challenging treatments, ceramic abutments provide more natural outcomes than traditional titanium abutments. In two-piece ceramic abutments, the presence of titanium inserts can overcome the brittleness of ceramic, improve fracture resistance, and prevent wear and damage to the internal connection of the implant fixture. In contrast, the monolithic nature of these restorations prevents some mechanical complications including ceramic chipping. Furthermore, extraoral cementation reduces the possibility of peri-implantitis. Although hybrid abutments are recommended by *in vitro* studies as a promising treatment option, there is a strong need for long-term clinical studies to evaluate the clinical performance of these abutments. Moreover, soft-tissue reaction to the bonding gap, especially in bone-level implants in the esthetic zone, remains unknown. Therefore, this type of abutment should be used bearing the current limitations in mind.

Authors' Contributions

Azam Sadat Mostafavi supported the manuscript and revised the final version.
Hamid Mojtahedi contributed to language editing, proofreading, writing assistance, and technical editing.
Afrooz Javanmard wrote the manuscript and designed the study, reviewed the literature and clinical evidence of research.

Conflict of Interest

None declared.

References

1 Sailer I, Zembic A, Jung RE, Hämmerle CH, Mattiola A. Single-tooth implant reconstructions: esthetic factors influencing the decision between titanium and zirconia abutments in anterior regions. Eur J Esthet Dent 2007;2(3):296–310
2 Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. J Prosthet Dent 2017;117(4):499–506
3 Gehrke P, Johannson D, Fischer C, Stawarczyk B, Beuer F. In vitro fatigue and fracture resistance of one- and two-piece CAD/CAM zirconia implant abutments. Int J Oral Maxillofac Implants 2015;30(3):546–554
4 Guilherme NM, Chung KH, Flinn BD, Zheng C, Raigrodski AJ. Assessment of reliability of CAD-CAM tooth-colored implant custom abutments. J Prosthet Dent 2016;116(2):206–213
5 Elsayed A, Wille S, Al-Akhali M, Kern M. Effect of fatigue loading on the fracture strength and failure mode of lithium disilicate and zirconia implant abutments. Clin Oral Implants Res 2018;29(1):20–27
6 Baldassarri M, Hjerppe J, Romeo D, Fickl S, Thompson VP, Stappert CFJ. Marginal accuracy of three implant-ceramic abutment configurations. Int J Oral Maxillofac Implants 2012;27(3):537–543
7 Cavusoglu Y, Akça K, Gürbüz R, Cehreli MC. A pilot study of joint stability at the zirconium or titanium abutment/titanium implant interface. Int J Oral Maxillofac Implants 2014;29(2):338–343
8 Stimmelmayr M, Edelhoff D, Güth JF, Erdelt K, Happe A, Beuer F. Wear at the titanium-titanium and the titanium-zirconia implant-abutment interface: a comparative in vitro study. Dent Mater 2012;28(12):1215–1220
9 Chun H-J, Yeo IS, Lee JH, et al. Fracture strength study of internally connected zirconia abutments reinforced with titanium inserts. Int J Oral Maxillofac Implants 2015;30(2):346–350
10 Chee W, Felton DA, Johnson PF, Sullivan DY. Cemented versus screw-retained implant prostheses: which is better? Int J Oral Maxillofac Implants 1999;14(1):137–141
11 Gervais MJ, Wilson PR. A rationale for retrievability of fixed, implant-supported prostheses: a complication-based analysis. Int J Prosthodont 2007;20(1):13–24
12 Hussien ANM, Rayyan MM, Sayed NM, Segaan LG, Goodacre CJ, Kattadiyil MT. Effect of screw-access channels on the fracture resistance of 3 types of ceramic implant-supported crowns. J Prosthet Dent 2016;116(2):214–220
13 Lee A, Okayasu K, Wang H-L. Screw- versus cement-retained implant restorations: current concepts. Implant Dent 2010;19(1):8–15
14 Hebel KS, Gajjar RC. Cement-retained versus screw-retained implant restorations: achieving optimal occlusion and esthetics in implant dentistry. J Prosthet Dent 1997;77(1):28–35
15 Sailer I, Mühlemann S, Zwahlen M, Hämmerle CHF, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 2012;23(Suppl 6) :163–201
16 Rajan M, Gunaseelan R. Fabrication of a cement- and screw-retained implant prosthesis. J Prosthet Dent 2004;92(6):578–580
17 Guichet DL, Caputo AA, Choi H, Sorensen JA. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. Int J Oral Maxillofac Implants 2000;15(2):239–246
18 Wilson TG Jr, Valderrama P, Burbano M, et al. Foreign bodies associated with peri-implantitis human biopsies. J Periodontol 2015;86(1):9–15
19 Pauletto N, Lahiffe BJ, Walton JN. Complications associated with excess cement around crowns on osseointegrated implants: a clinical report. Int J Oral Maxillofac Implants 1999;14(6):865–868
20 Gapski R, Neugeboren N, Pomeranz AZ, Reissner MW. Endosseous implant failure influenced by crown cementation: a clinical case report. Int J Oral Maxillofac Implants 2008;23(5):943–946
21 McGlumphy EA, Papazoglou E, Riley RL. The combination implant crown: a cement- and screw-retained restoration. Compendium 1992;13(1):34–36, 38 passim

22 Uludag B, Celik G. Fabrication of a cement- and screw-retained multiunit implant restoration. J Oral Implantol 2006;32(5):248–250
23 Park JI, Lee Y, Lee JH, Kim YL, Bae JM, Cho HW. Comparison of fracture resistance and fit accuracy of customized zirconia abutments with prefabricated zirconia abutments in internal hexagonal implants. Clin Implant Dent Relat Res 2013;15(5):769–778
24 Kim S, Kim HI, Brewer JD. Monaco EA Jr. Comparison of fracture resistance of pressable metal ceramic custom implant abutments with CAD/CAM commercially fabricated zirconia implant abutments. J Prosthet Dent 2009;101(4):226–230
25 Martínez-Rus F, Ferreiroa A, Özcan M, Bartolomé JF, Pradíes G. Fracture resistance of crowns cemented on titanium and zirconia implant abutments: a comparison of monolithic versus manually veneered all-ceramic systems. Int J Oral Maxillofac Implants 2012;27(6):1448–1455
26 Fabbri G, Fradeani M, Dellificorelli G. De Lorenzi M, Zarone F, Sorrentino R. Clinical Evaluation of the Influence of Connection Type and Restoration Height on the Reliability of Zirconia Abutments: A Retrospective Study on 965 Abutments with a Mean 6-Year Follow-Up. Int J Periodontics Restorative Dent 2017;37(1):19–31
27 Edelhoff D, Schweiger J, Prandtner O, Stimmelmayr M, Güth JF. Metal-free implant-supported single-tooth restorations. Part II: hybrid abutment crowns and material selection. Quintessence Int 2019;50(4):260–269
28 Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008;24(3):299–307
29 Albakry M, Guazzato M, Swain MV. Biaxial flexural strength, elastic moduli, and x-ray diffraction characterization of three pressable all-ceramic materials. J Prosthet Dent 2003;89(4):374–380
30 Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics. Dent Mater 2004;20(5):441–448
31 Kurtulmus-Yilmaz S, Ulusoy M. Comparison of the translucency of shaded zirconia all-ceramic systems. J Adv Prosthodont 2014;6(5):415–422
32 Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dent Mater 2014;30(5):564–569
33 Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015;114(4):587–593
34 Duarte S, Sartori N, Phark J-H. Ceramic-reinforced polymers: CAD/CAM hybrid restorative materials. Curr Oral Health Rep 2016;3(3):198–202
35 Vita Enamic Implant Solutions. Available at: https://cdn.vivarep.com/contrib/vivarep/media/pdf/4_4646_ENAMICImplantSolutionsBrochure_20170830210817381.pdf. Accessed August 4, 2021
36 Invoclar Vivadent. Available at: https://www.ivoclarvivadent.com/en/p/all/telio-cad/telio-cad. Accessed August 4, 2021
37 VITA CAD-Temp IS. Available at: https://www.vita-zahnfabrik.com/en/Dentist-Solutions/CAD/CAM-fabrication/Implant-supported-restorations/VITA-CAD-Temp-IS-38740,27568.html. Accessed August 4, 2021
38 Ebert A, Hedderich J, Kern M. Retention of zirconia ceramic copings bonded to titanium abutments. Int J Oral Maxillofac Implants 2007;22(6):921–927
39 Moon J-E, Kim S-H, Lee J-B, et al. Effects of airborne-particle abrasion protocol choice on the surface characteristics of monolithic zirconia materials and the shear bond strength of resin cement. Ceram Int 2016;42(1):1552–1562
40 Garcia Fonseca R, de Oliveira Abi-Rached F, dos Santos Nunes Reis JM, Rambaldi E, Baldissara P. Effect of particle size on the flexural strength and phase transformation of an airborne-particle abraded yttria-stabilized tetragonal zirconia polycrystal ceramic. J Prosthet Dent 2013;110(6):510–514
41 Zhang Y, Pajares A, Lawn BR. Fatigue and damage tolerance of Y-TZP ceramics in layered biomechanical systems. J Biomed Mater Res B Appl Biomater 2004;71(1):166–171
42 Skienhe H, Habchi R, Ounsi H, Ferrari M, Salameh Z. Evaluation of the effect of different types of abrasive surface treatment before and after zirconia sintering on its structural composition and bond strength with resin cement. BioMed Res Int 2018;2018:1803425 doi: 10.1155/2018/1803425
43 Hallmann L, Ulmer P, Lehmann F, et al. Effect of surface modifications on the bond strength of zirconia ceramic with resin cement resin. Dent Mater 2016;32(5):631–639
44 Song J-Y, Park SW, Lee K, Yun KD, Lim HP. Fracture strength and microstructure of Y-TZP zirconia after different surface treatments. J Prosthet Dent 2013;110(4):274–280
45 Özcan M, Melo RM, Souza RO, Machado JP, Felipe Valandro L, Botttino MA. Effect of air-particle abrasion protocols on the biaxial flexural strength, surface characteristics and phase transformation of zirconia after cyclic loading. J Mech Behav Biomed Mater 2013;20:19–28
46 de Oyagüe RC, Monticelli F, Toledano M, Osorio E, Ferrari M, Osorio R. Influence of surface treatments and resin cement selection on bonding to densely-sintered zirconium-oxide ceramic. Dent Mater 2009;25(2):172–179
47 Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Selective infiltration-etching technique for a strong and durable bond of resin cements to zirconia-based materials. J Prosthet Dent 2007;98(5):379–388
48 Akhavan Zanjani V, Ahmadi H, Nateghifard A, et al. Effect of different laser surface treatment on microshear bond strength between zirconia ceramic and resin cement. J Investig Clin Dent 2015;6(4):294–300
49 Jevnikar P, Krnel K, Kocjan A, Funduk N, Kosmac T. The effect of nano-structured alumina coating on resin-bond strength to zirconia ceramics. Dent Mater 2010;26(7):688–696
50 Blatz MB, Chiche G, Holst S, Sadan A. Influence of surface treatment and simulated aging on bond strengths of luting agents to zirconia. Quintessence Int 2007;38(9):745–753
51 Elsayed A, Younes F, Lehmann F, Kern M. Tensile bond strength of so-called universal primers and universal multimode adhesives to zirconia and lithium disilicate ceramics. J Adhes Dent 2017;19(3):221–228
52 Mehl C, Zhang Q, Lehmann F, Kern M. Retention of zirconia on titanium in two-piece abutments with self-adhesive resin cements. J Prosthet Dent 2018;120(2):214–219
53 Ozcan M, Nijhuis H, Valandro LF. Effect of various surface conditioning methods on the adhesion of dual-cure resin cement with MDP functional monomer to zirconia after thermal aging. Dent Mater J 2008;27(1):99–104
54 Colares RC, Neri JR, Souza AM, Pontes KM, Mendonça JS, Santiago SL. Effect of surface pretreatments on the microtensile bond strength of lithium-disilicate ceramic repaired with composite resin. Braz Dent J 2013;24(4):349–352
55 Kursoglu P, Motro PFK, Yurdaguven H. Shear bond strength of resin cement to an acid etched and a laser irradiated ceramic surface. J Adv Prosthodont 2013;5(2):98–103
56 Nagai T, Kawamoto Y, Kakehashi Y, Matsumura H. Adhesive bonding of a lithium disilicate ceramic material with resin-based luting agents. J Oral Rehabil 2005;32(8):598–605
57 Türk T, Saraç D, Saraç YS, Elekdağ-Türk S. Effects of surface conditioning on bond strength of metal brackets to all-ceramic surfaces. Eur J Orthod 2006;28(5):450–456
58 Kiyan VH, Saraceni CH, da Silveira BL, Aranha AC, Eduardo CdaP. The influence of internal surface treatments

on tensile bond strength for two ceramic systems. Oper Dent 2007;32(5):457–465
59 Kim B-K, Bae HE, Shim JS, Lee KW. The influence of ceramic surface treatments on the tensile bond strength of composite resin to all-ceramic coping materials. J Prosthet Dent 2005;94(4):357–362
60 Panah FG, Rezai SMM, Ahmadian L. The influence of ceramic surface treatments on the micro-shear bond strength of composite resin to IPS Empress 2. J Prosthodont 2008;17(5):409–414
61 Brum R, Mazur R, Almeida J, Borges G, Caldas D. The influence of surface standardization of lithium disilicate glass ceramic on bond strength to a dual resin cement. Oper Dent 2011;36(5):478–485
62 Lise DP, Perdigão J, Van Ende A, Zidan O, Lopes GC. Microshear bond strength of resin cements to lithium disilicate substrates as a function of surface preparation. Oper Dent 2015;40(5):524–532
63 Menees TS, Lawson NC, Beck PR, Burgess JO. Influence of particle abrasion or hydrofluoric acid etching on lithium disilicate flexural strength. J Prosthet Dent 2014;112(5):1164–1170
64 Della Bona A, Anusavice KJ. Microstructure, composition, and etching topography of dental ceramics. Int J Prosthodont 2002;15(2):159–167
65 Abi-Rached FdeO, Fonseca RG, Haneda IG, de Almeida-Júnior AA, Adabo GL. The effect of different surface treatments on the shear bond strength of luting cements to titanium. J Prosthet Dent 2012;108(6):370–376
66 Fonseca RG, Haneda IG, Almeida-Júnior AA, de Oliveira Abi-Rached F, Adabo GL. Efficacy of air-abrasion technique and additional surface treatment at titanium/resin cement interface. J Adhes Dent 2012;14(5):453–459
67 Guilherme N, Wadhwani C, Zheng C, Chung KH. Effect of surface treatments on titanium alloy bonding to lithium disilicate glass-ceramics. J Prosthet Dent 2016;116(5):797–802
68 Egoshi T, Taira Y, Soeno K, Sawase T. Effects of sandblasting, H2SO4/HCl etching, and phosphate primer application on bond strength of veneering resin composite to commercially pure titanium grade 4. Dent Mater J 2013;32(2):219–227
69 Linkevicius T, Caplikas A, Dumbryte I, Linkeviciene L, Svediene O. Retention of zirconia copings over smooth and airborne-particle-abraded titanium bases with different resin cements. J Prosthet Dent 2019;121(6):949–954
70 von Maltzahn NF, Holstermann J, Kohorst P. Retention forces between titanium and zirconia components of two-part implant abutments with different techniques of surface modification. Clin Implant Dent Relat Res 2016;18(4):735–744
71 Qeblawi DM, Muñoz CA, Brewer JD, Monaco EA Jr. The effect of zirconia surface treatment on flexural strength and shear bond strength to a resin cement. J Prosthet Dent 2010;103(4):210–220
72 Blatz MB, Phark JH, Ozer F, et al. In vitro comparative bond strength of contemporary self-adhesive resin cements to zirconium oxide ceramic with and without air-particle abrasion. Clin Oral Investig 2010;14(2):187–192
73 Bernal G, Okamura M, Muñoz CA. The effects of abutment taper, length and cement type on resistance to dislodgement of cement-retained, implant-supported restorations. J Prosthodont 2003;12(2):111–115
74 Abbo B, Razzoog ME, Vivas J, Sierraalta M. Resistance to dislodgement of zirconia copings cemented onto titanium abutments of different heights. J Prosthet Dent 2008;99(1):25–29
75 Cano-Batalla J, Soliva-Garriga J, Campillo-Funollet M, Munoz-Viveros CA, Giner-Tarrida L. Influence of abutment height and surface roughness on in vitro retention of three luting agents. Int J Oral Maxillofac Implants 2012;27(1):36–41
76 Silva CEP, Soares S, Machado CM, et al. Effect of CAD/CAM abutment height and cement type on the retention of zirconia crowns. Implant Dent 2018;27(5):582–587
77 Mehl C, Harder S, Steiner M, Vollrath O, Kern M. Influence of cement film thickness on the retention of implant-retained crowns. J Prosthodont 2013;22(8):618–625
78 Nejatidanesh F, Savabi O, Jabbari E. Effect of surface treatment on the retention of implant-supported zirconia restorations over short abutments. J Prosthet Dent 2014;112(1):38–44
79 Nejatidanesh F, Savabi O, Shahtoosi M. Retention of implant-supported zirconium oxide ceramic restorations using different luting agents. Clin Oral Implants Res 2013;24(Suppl A100) :20–24
80 Abrahamsson I, Berglundh T, Glantz PO, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol 1998;25(9):721–727
81 Mehl C, Gassling V, Schultz-Langerhans S, et al. Influence of four different abutment materials and the adhesive joint of two-piece abutments on cervical implant bone and soft tissue. Int J Oral Maxillofac Implants 2016;31(6):1264–1272
82 Mehl C, Kern M, Schütte AM. Kadem LF, Selhuber-Unkel C. Adhesion of living cells to abutment materials, dentin, and adhesive luting cement with different surface qualities. Dent Mater 2016;32(12):1524–1535
83 Alsahhaf A, Spies BC, Vach K, Kohal RJ. Fracture resistance of zirconia-based implant abutments after artificial long-term aging. J Mech Behav Biomed Mater 2017;66:224–232
84 Conejo J, Kobayashi T, Anadioti E, Blatz MB. Performance of CAD/CAM monolithic ceramic implant-supported restorations bonded to titanium inserts: a systematic review. Eur J Oral Implantology 2017;10(Suppl 1):139–146
85 Nouh I, Kern M, Sabet AE, Aboelfadl AK, Hamdy AM, Chaar MS. Mechanical behavior of posterior all-ceramic hybrid-abutment-crowns versus hybrid-abutments with separate crowns-a laboratory study. Clin Oral Implants Res 2019;30(1):90–98
86 Roberts EE, Bailey CW, Ashcraft-Olmscheid DL, Vandewalle KS. Fracture resistance of titanium-based lithium disilicate and zirconia implant restorations. J Prosthodont 2018;27(7):644–650
87 Pjetursson BE, Karoussis I, Bürgin W, Brägger U, Lang NP. Patients' satisfaction following implant therapy. A 10-year prospective cohort study. Clin Oral Implants Res 2005;16(2):185–193
88 Rosentritt M, Rembs A, Behr M, Hahnel S, Preis V. In vitro performance of implant-supported monolithic zirconia crowns: Influence of patient-specific tooth-coloured abutments with titanium adhesive bases. J Dent 2015;43(7):839–845
89 Gehrke P, Alius J, Fischer C, Erdelt KJ, Beuer F. Retentive strength of two-piece CAD/CAM zirconia implant abutments. Clin Implant Dent Relat Res 2014;16(6):920–925
90 Bankoğlu Güngör M, Karakoca Nemli S. The effect of resin cement type and thermomechanical aging on the retentive strength of custom zirconia abutments bonded to titanium inserts. Int J Oral Maxillofac Implants 2018;33(3):523–529
91 Zenthöfer A, Rues S, Krisam J, Rustemeyer R, Rammelsberg P, Schmitter M. Debonding forces for two-piece zirconia abutments with implant platforms of different diameter and use of different luting strategies. Int J Oral Maxillofac Implants 2018;33(5):1041–1046
92 Freifrau von Maltzahn N, Bernard S, Kohorst P. Two-part implant abutments with titanium and ceramic components: surface modification affects retention forces-an in-vitro study. Clin Oral Implants Res 2019;30(9):903–909
93 Nilsson A, Johansson LÅ, Lindh C, Ekfeldt A. One-piece internal zirconia abutments for single-tooth restorations on narrow and regular diameter implants: a 5-year prospective follow-up study. Clin Implant Dent Relat Res 2017;19(5):916–925
94 Sui X, Wei H, Wang D, et al. Experimental research on the relationship between fit accuracy and fracture resistance of zirconia abutments. J Dent 2014;42(10):1353–1359

95 Ti bases for zirconia abutments. Available at: https://lmtmag.com/products/1686. Accessed August 4, 2021
96 https://www.ivoclarvivadent.com/en/p/all/ips-emax-system-dentists/ips-emax-cad-chairside#
97 Dentsply Sirona. CEREC mining and grinding units. Available at: https://my.cerec.com/en-us/products/milling-grinding.html, Accessed August 4, 2021