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REVIEW

How Much is Stable the Bonding of CAD-CAM Implant-Supported All-Ceramic Restorations to Titanium Bases Clinically? A Systematic Review

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Abstract: The rapid advancement of digital technologies and the introduction of new ceramic materials have largely attributed to the notable transition from metal-ceramic to all-ceramic implant restorations bonded to Ti-bases. The purpose of this review was to evaluate all clinical studies reporting on the bond stability between CAD-CAM implant-supported all-ceramic restorations and Ti-bases. The review was directed according to the PRISMA guidelines to answer the focused question "How much is the stability and durability of the resin bond between implant-supported fixed CAD-CAM ceramic restorations and Ti- bases clinically?". The PubMed, Google Scholar, and Cochrane databases were investigated to identify related clinical studies. Human studies assessing at least 10 patients restored with implant-supported fixed CAD-CAM ceramic restorations luted to prefabricated Ti-bases with a mean follow-up of at least 1 year and published in an English-language up to Sep. 2024 were included. The restorations could be single crown, fixed dental prosthesis, or full-arch fixed prosthesis. The search yielded 5,190 records; of these, 59 full-text articles were evaluated based on eligibility criteria. Ultimately, 40 studies were included. All 40 studies demonstrated low debonding rates from Ti-bases for single copings, multi-unit fixed dental prostheses, and full arch zirconia prostheses. Based on the limited evidence available, different factors were blamed for the debonding incidence, such as Ti-base height, geometry, luting agent, inadequacy of passive fit and biomechanical patient- and prosthesis-related factors. CAD-CAM implant-supported all-ceramic restorations bonded to Ti-bases demonstrated relatively high bond stability during observation period ranging from 1 to 7.5 years. More well-designed clinical research with long-term observation periods is highly recommended.
Keywords: dental implant, bond stability, Ti-base, ceramic restoration, debonding

Introduction

Osseointegration has revolutionized dental treatments, making implant-supported prostheses a popular choice for replacing missing teeth. These treatments boast impressive long-term implant survival rates, often exceeding 95% over a decade.[1–3]

Traditionally, metal-based handcrafted restorations with feldspathic ceramics were the standard. However, advancements in CAD-CAM technology, combined with the increased demand for esthetic solutions, have expanded the possibilities for all-ceramic reconstructions, making them more affordable and efficient to produce.[4]

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramics are increasingly popular in implant dentistry due to their superior mechanical properties, low water solubility, reduced bacterial adherence, superior corrosion resistance, and biocompatibility.[5,6] Lithium disilicate glass-ceramic is another ceramic material that possesses excellent mechanical properties and translucency; therefore, it is increasingly used for making screw-retained implant crowns with various CAD-CAM systems. [7]

The industrialization of dental prostheses with CAD-CAM technology has encouraged implant manufacturers to create components compatible with the fully digital process, like titanium base abutment (Ti-base).[8] Ti-base abutment, which is a prefabricated abutment with an incorporated digital library, stands out for their uniqueness and distinction

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from customizable abutments due to their association with a digital library. Ti-bases, which are available in the digital library as open STL files, offer a range of geometries, heights, contours, and engaging and non-engaging connections, according to the restorative needs.[9] After selecting a Ti-base and designing the full prosthesis or intermediate coping, the eventual STL file is delivered for milling. This milled restoration or coping fits over the Ti-base with minimal adjustment needed, ensuring a close fit before cementation.[9] The literature presents various names for this prefabricated abutment, such as Ti-base abutment, titanium-bonding base, titanium insert, hybrid abutment, cementing cap, and titanium cylinder.[8] The author used the “Ti-base” term consistently in this review.

Ti-bases present with several merits. They assist in transitioning to a digital workflow, either fully or partially, thus leading to a reduction in production costs and to a significant improvement in time efficiency.[4,10] In addition, zirconia abutments combined with Ti-bases address some of the issues related to one-piece zirconia abutments, which have shown a higher fracture rate compared to metal abutments, as well as increased wear at the implant connection.[11] Furthermore, combining a Ti-base with either a ceramic meso-structure (known as 2-piece hybrid abutment) or a fully contoured restoration (known as a 1-piece hybrid-abutment-restoration) transforms a standard component into a customized one that would support the peri-implant soft tissue and enhance esthetics.[12] Moreover, with this screwmentable hybrid-abutment-restoration, bonding process can be carried out in a controlled laboratory setting, with no risk of leftover cement.[13]

While short-term clinical outcomes for Ti-base implant-supported ceramic restorations were encouraging,[9,14] there are concerns about the long-term bonding stability. In vitro studies simulating five years of clinical use showed some crowns detaching from the titanium-base abutments,[12,15] and others displayed marginal gaps and slight movements between the components.[15] Provided the adhesive bond is strategically placed beneath the peri-implant mucosa to hide the titanium in various clinical scenarios, this positioning may pose biological risks due to the potential for increased bacterial buildup if the adhesive bond degrades. Additionally, implant restorations with marginal misfits can result in greater crestal bone loss compared to those that fit accurately.[16] Therefore, the debonding issue is the origin of most complications and, subsequently, failures.

Since concerns have been raised about the weak bond strength between the ceramic restoration and Ti-base,[12,15] several laboratory studies and a recent systematic review[7,13,15,17,18] have investigated the bond strength and the factors that impacted the bond strength between ceramic restorations and Ti-bases; however, to the best of author’s knowledge, there is no systematic review that explored the clinical stability or durability of the resin bond between implant-supported fixed CAD-CAM ceramic restorations and Ti-bases.

There is a scarcity of clinical research on the failure of ceramic prosthesis bonding to Ti-bases, since the Ti-base abutment concept is still a new treatment available in the market, and because the initial bonding failure usually presents as a micromovement that may not be detected except with microscopic evaluation after restoration removal, rending this difficult.[18] In addition, clinical studies are costly and take a lot of time; however, they do answer on the real clinical behavior of different restorations being assessed.[19] Therefore, this systematic review aimed to review all clinical studies reporting on the bond stability and durability between implant-supported fixed CAD-CAM ceramic restorations and Ti-bases from single crowns to full-arch prostheses; so as to deliver reliable clinical guidelines for a stable bonding protocol. The bond was considered stable if the restoration did not detach from Ti-base for the duration of the study.

Methods

Protocol

This systematic review was directed according to the guidelines delineated in the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)[20] using the Population, Intervention, Comparison and Outcome (PICO) method.[21] According to the PICO framework (population: implant-supported fixed CAD-CAM ceramic restorations, intervention: adhesion to Ti-bases, comparison: bonding protocol not applicable, and outcome: bond stability/ durability. As the current study is a systematic review, there was no need to gain approval from the ethics committee.

Focused Question

The focused question of the present review was: “How much is the stability and durability of the resin bond between implant-supported fixed CAD-CAM ceramic restorations and Ti-bases clinically?”

Eligibility Criteria and Exclusion Criteria

The inclusion and exclusion criteria were set based on PICO (Population, Intervention, Comparison, Outcome) guidelines as presented in Table 1.

Information Sources and Search Strategy

The PubMed, Google Scholar, and Cochrane databases were investigated on September 21, 2024. Additional searching was executed in the references of included manuscripts, some related systematic reviews, and on the web sites of some journals: Clinical Implant Dentistry and Related Research; Clinical Oral Implant research; The International Journal of Oral & Maxillofacial Implants; The International Journal of Prosthodontics; Journal of Prosthetic Dentistry; Journal of Prosthodontics; Journal of Dentistry; Dental Materials; and Journal of Oral Implantology. Representative keywords are presented in Table 2.

Selection Process

The author executed the literature search by firstly screening through titles and abstracts; then, full-text articles were screened if title and abstract did not offer sufficient information. The author then read the full-texts of the included articles. Figure 1 displays the flowcharts of manuscripts identification and inclusion.

Data Collection Process

The author read the full-texts of the included articles and extracted all the relevant data of each one, using pre-determined fields in a uniform data extraction sheet.

Table 1 Inclusion and Exclusion Criteria for Clinical Studies

Criteria	Inclusion Criteria	Exclusion Criteria
Timespan	Between 1 Jan. 2000 and Sep. 2024	
Publishing aspects	Studies published in international peer reviewed journals in an English -language	
Study design	*RCTs *Clinical controlled trials *Prospective or retrospective cohort *Prospective case series *≥ 10 patients	*Animal studies *Case series or reports < 10 patients
Type of patients (P)	*Patients restored with implant-supported CAD-CAM fixed ceramic restorations luted to prefabricated Ti-bases. The restorations could be single crown, fixed dental prosthesis, or full-arch fixed prosthesis. *When multiple studies of the same population were recognized, only the most recent study was included.	*Patients with tooth-supported ceramic restorations *Patients with customized or cast Ti-abutments or solid Z abutments *Not CAD-CAM ceramic restorations *Studies reporting on subperiosteal or zirconia implants *Inadequate reporting on drop-outs and number of patients at follow-up
Type of interventions (I)	Studies reporting on the resin bonding of ceramic restorations to Ti-base	
Type of control (C)	No comparison or control groups were specified	
Type of outcomes (O)	*Studies with a mean follow up ≥12 months after restoration delivery *Studies reporting about the prosthetic outcomes of ceramic restorations including the bond stability, restoration survival rates, and /or any incidence of prosthetic complications like debonding	*Studies with a mean follow-up < 12 months *Survey/ telephone call follow-ups *Studies not reporting about the prosthetic outcomes of ceramic restorations

Abbreviation: RCTs, randomized controlled trials.

Table 2 Systematic Review Search Strategy

Electronic Databases and Libraries	MeSH Search Terms and Free-Text Words
PubMed, Google Scholar, and Cochrane databases	((Titanium base) OR (ti-base) OR (titanium inserts) OR (hybrid-abutment) OR (hybrid-abutment-crown) AND (Zirconia) OR (Zirconium) OR (Zircon*) OR (Y-TZP) OR (TZP) OR (ZrO_2) OR (PSZ) OR (FSZ) OR (CSZ) OR (Ce-TZP) OR (lithium disilicate) OR (lithium silicate) OR (IPS e-max) OR (IPS Empress) OR (pressed ceramic) OR (ceramic) AND (retention) OR (loss of retention) OR (survival rate) OR (longevity) OR (bond stability) OR (bond strength) OR (tensile strength) OR (tensile force) OR (pull-out retention force) OR (shear bond strength) OR (debonding) OR (micromovement) AND (implant)).

Abbreviation: Ti-base, titanium base.

Data Extraction

The gathered data for included studies comprised the authors' name (year), study design, number of patients and restorations, restoration type, the evaluated ceramic materials, the used Ti-base system, the pre-treatment protocol and bonding system, follow-up time, restoration survival rate, number or rate of debonding incidence, and other prosthetic complications.

Risk of Bias Assessment

The risk of bias of the included Randomized controlled trials (RCTs) was assessed by the Cochrane risk of bias revised tool (RoB 2),[22] the ROBINS-I tool was used to assess the non-randomized controlled clinical trials,[23] and the Joanna Briggs Institute's (JBI) critical appraisal tool was used to evaluate the one-arm case series studies.[24]

Synthesis Methods

Since heterogeneity was detected among the included studies, a meta-analysis was not conducted. Instead, summarization of the pertinent clinical studies was implemented.

Results

Study Selection

A total of 5,186 records were identified from electronic literature search through Sep. 21, 2024, whereas 4 records were identified after hand searching through references of included studies. After the duplicate removal, 3,184 records remained for screening based on titles and abstracts. Of these, 59 full-text articles were evaluated based on eligibility criteria. Ultimately, 40 studies[25–64] were included in this systematic review as shown in Figure 1 after exclusion of eighteen articles[65–82] for reasons outlined in Table 3 and one could not be retrieved.[83]

Study Characteristics

These comprised twenty retrospective investigations, twelve RCTs, and eight prospective. Of the 40 included studies, 29 studies were on zirconia framework bonded to Ti-bases, 7 studies were on lithium disilicate glass ceramic single copings bonded to Ti-bases, 3 studies were on both zirconia and lithium disilicate, and one was on non-specified CAD-CAM ceramic restorations. The ceramic material used for multi-unit fixed dental prostheses (FDPs) and full-arch prostheses was only zirconia, while zirconia and lithium disilicate glass ceramics were used for single copings.

Regarding the used bonding system, 17 studies did not specify the used bonding system, while the reported utilized resin cements were mainly dual-cure and only two studies utilized self-cure resin cement.

While 29 studies did not specify the type of bonding surfaces' pre-treatment, the rest of the studies demonstrated that the pre-treatment ranged from no pre-treatment to sandblasting with 50µm alumina particles at 1- to 2.5-bar pressure for zirconia and Ti-bases, with or without MDP-containing primers application. Lithium disilicate bonding surfaces were usually etched with hydrofluoric acid and silanized prior to bonding.

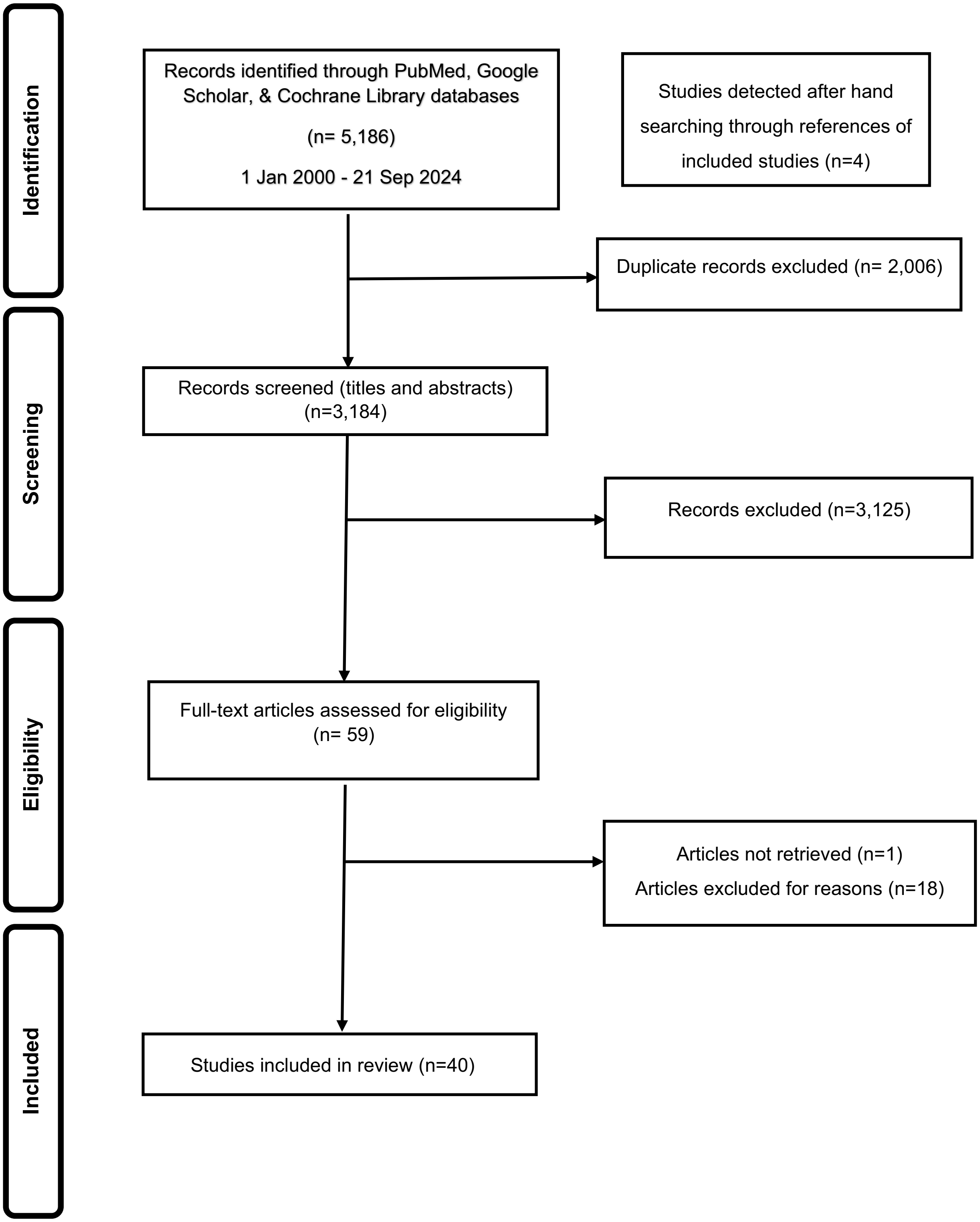

Figure 1 Flowchart viewing the studies identification and inclusion method.

In this systematic review, success of the bond was decided as the ceramic restoration remaining in place, luted to Ti-base, without any visible debonding in the study's observation period. Survival was described as original restoration staying in situ at the time of follow-up with or without adjustment during the investigation period. If a restoration debonded but could be favorably rebonded, the survival rate was not affected. Prosthetic complication was designated as

Table 3 Studies Excluded from the Second Stage of Searching

Study	Reason for Exclusion
Oliva et al 2012[65]	The use of Ti-bases or cylinders for full-arch zirconia not reported
Moscovitch 2015[66]	The use of Ti-bases or cylinders not reported
Larsson & Steyern 2016[67]	Ti-stock preparable abutment was used not Ti-base
Joda & Bragger 2016[68]	Same patients followed in a more recent study (Joda et al 2018)
Lin et al 2020[69]	CAD-CAM customized Ti-base utilized not prefabricated
Gierthmuehlen et a. 2020[70]	LD restorations were pressed not milled CAD-CAM
Linkevicius et al 2020[71]	Prosthetic outcomes not reported
Iglhaut et al 2021[72]	Prosthetic outcomes not reported
Krawiec et al 2021[73]	Prosthetic outcomes not reported
Mihali et al 2021[74]	LD restorations were pressed not milled CAD-CAM
Finelle et al 2021[75]	Prosthetic outcomes not reported
Derksen et al 2021 a[76]	Same patients followed in a more recent study (Derksen & Wismeijer 2023)
Derksen et al 2021 b[77]	Same patients followed in a more recent study (Derksen & Wismeijer 2023)
Linkevicius et al 2022[78]	Prosthetic outcomes not reported
Cakan & Ozkan 2022[79]	Ti-stock preparable abutment was used not Ti-base
Khamis & Zakaria 2022[80]	Ti-stock preparable abutment was used not Ti-base
Farrag & Khamis 2023[81]	Prosthetic outcomes not reported
Naumann et al 2023[82]	LD copings were pressed not milled CAD-CAM

Abbreviations: LD, lithium disilicate; Ti, titanium.

any unsatisfactory or unpredicted event happening during the investigation period but did not mandate remaking of restoration. These were documented but, for the aims of this review, were not considered in the success rates that focused on bond stability. Studies' characteristics are presented in Table 4. An overview of the utilized resin cements is presented in Table 5.

Data Synthesis

Single Implant Restorations

Twenty-nine studies reported on prosthetic outcomes of single ceramic copings bonded to Ti-bases, either hybrid-abutment crowns (1-piece) or hybrid-abutments (2-piece). A total of 2,056 single ceramic copings were evaluated in this review, 711 were lithium disilicate copings and the rest were zirconia. Notably, 18 debonding events were reported (10 zirconia, 8 lithium disilicate) during follow-up ranging from 1 to 7.5 years. A recent RCT[25] reported on one occurrence of de-cementation of posterior zirconia crown from Ti-base out of 41 crowns in the first year of function, and it was successfully e-cemented during the 3-year observation period. Another recent RCT[26] reported 2 of 27 posterior zirconia crowns de-cemented from Ti-bases during the 4-year observation period. The authors did not report on the outcomes of these crowns. In a prospective study,[27] four events (5.3%) of debonding between posterior zirconia crowns and Ti-bases were reported during the 2-year observation period. These events were encountered only with crowns luted with dual-cure resin cement (RelyX Ultimate) and were successfully re-bonded with self-cure resin cement (Multilink Hybrid Abutment) for the duration of study.[27] In addition, a 3-year retrospective study[28] reported two of the 106 posterior zirconia abutments de-bonded from Ti-bases. They were successfully re-bonded for the duration of the study.[28] Another retrospective study[29] reported 1 out of 82 zirconia copings de-bonded from Ti-base during the 6-year observation period, and the coping was successfully re-bonded for the duration of the study. In a further recent retrospective study,[30] eight events (1.3%) of debonding between posterior milled lithium disilicate crowns and Ti-bases were recorded through a mean observation period of 6 years. The authors did not report on the outcomes of these crowns.[30]

Multi-Unit FDPs

A total of 107 multi-unit zirconia FDPs besides approximately 52 multi-unit FDPs (supported by 105 implants[31]), were evaluated in this review. Nine events of debonding of zirconia restorations from Ti-bases were reported during a follow-up

Table 4 Study Characteristics of the Reviewed Studies

Study	Study Design	No. of Patients (Restorations) at End of Observation	Restoration Type	Ceramic Material Bonded to Ti-base	Ti-base Type/ Geometry/ ATTACHMENT Height	Surface Pre-Treatment	Luting Agent	Mean Follow up (Year or Month)	Overall Restoration Survival Rate (%)	Ti-Base Debond	Other Prosthetic Complications
Limmer et al 2014[49]	Prospective	17 (17)	FA/ Max & mand/1 piece	MZ (Prettau)	Ti-cylinders (Astra Tech, OsseoSpeed)/NR	NR	NR	1 y	88	0	6 chipped teeth 2 abutment fracture 1 prosthesis fracture 1 loose abutment 1 debond of a single cementable unit
Carames et al 2015[50]	Retrospective	14 (26)	FA/ Max & mand/1 piece	MZ & PVZ (Prettau)	Ti- sleeves (NR)	NR	NR	3 to 24 mon	96	0	1 porcelain chipping
Venezia et al 2015[51]	Retrospective	18 (26)	FA/ Max & mand/1 piece	PVZ (Sagemax Zr; Sagemax Bioceramics Inc)	Ti-base (Straumann AG) implant level/NR	NR	Panavia F2	20.9 mon (mean)	100	0	3 porcelain chipping
Gonzalez & Triplett 2017[32]	Retrospective	40 (44)	FA/ Max & mand/1 piece	PVZ (Prettau)	Ti cylinders (Temporary Coping Multi-unit 29046, Nobel Biocare)/NR	NR	Variolink	33 mon (mean)	NR	2	6 minor porcelain chipping
Vizcaya 2018[53]	Retrospective	10 (20)	FA/Max & mand/1 piece	MZ & PVZ (Prettau)	Ti-cylinders (Conical Cemented Titanium Base, Zirkonzahn, Gais)/NR	NR	Multilink, Automix	2–7 y	100	0	1 pink porcelain chipping 2 screw loosening
Bidra et al 2018[33]	Retrospective	NR (2039)	FA/ Max & mand/1 piece	MZ (Prettau)	Ti cylinders (variety of implant systems) Implant level and abutment level/NR	NR	NR	5 y	99.3	6 (0.29%)	3 fractures of Ti-cylinders 6 fractures of prostheses
Box et al 2018[52]	Retrospective	NR (13)	FA/Max & mand/1 piece	MZ & PVZ (NR)	Ti-sleeves (NR)	NR	NR	20 mon	NR	0	4 loss of screw access filling 1 anterior wear (PVZ) 3 posterior wear 3 porcelain chipping (PVZ) 2 Wear of opposing arch (MZ)
Erhan Çömlekoğlu et al 2018[38]	RCT	16 (32)	SC/Anterior/2 piece	LD (E.max CAD Implant Abutment solutions, Ivoclar)	Tibase (Conelog, Camlog)/ 4.7 mm	NR	MHA	2 y	100	0	None
Tischler et al 2018[34]	Retrospective	128 (191)	FA/Max & mand./1 piece	MZ (Prettau)	Ti-cylinders (Biohorizons) Implant level and abutment level/NR	NR	NR	4 y	99.4	1	1 fracture of Z prostheses 2 screw fracture

(*Continued*)

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Table 4 (Continued).

Study	Study Design	No. of Patients (Restorations) at End of Observation	Restoration Type	Ceramic Material Bonded to Ti-base	Ti-base Type/ Geometry/ ATTACHMENT Height	Surface Pre-Treatment	Luting Agent	Mean Follow up (Year or Month)	Overall Restoration Survival Rate (%)	Ti-Base Debond	Other Prosthetic Complications
Linkevicius et al 2018[54]	Prospective	55(55)	SC/Posterior / 1 piece	MLD (IPS e.max; Ivoclar)	Ti-base (MIS, V3)/ 4.0 mm	NR	LinkAce	1 y	100	0	None
Mangano & Veronesi 2018[40]	RCT	25(25)	SC/Posterior/ 2 piece	MZ (Roland DWX-50)	Ti-base (Multitech, Leone,Italy)/ 4.0 and 6.0 mm	NR	NR	1 y	96	0	1 crown fracture
Joda et al 2018[41]	RCT	10(10)	SC/Posterior/ 1 piece	MLD (IPS e.max CAD, Ivoclar)	Ti-base (Variobase)/ 4.0 mm	NR	Multilink Implant	3 y	100	0	None
Cheng et al 2019[39]	RCT	NR (11)	SC/Molar/1 piece	PVZ (Ceramil zi or Ceramill Zolid; Amann Girrbach)	Ti-base (Variobase, Strauman)/NR	NR	RelyX Unicem	1 y	100	0	1 screw loosening
Caramês et al 2019[47]	Prospective clinical trial	138 (177)	FA/ Max & mand/1 piece	MZ & PVZ (Prettau)	Ti cylinders (Zimmer Biomet)/NR	NR	NR	1–2 y	99	0	2 framework fracture 18 controllable not major complications (not affect survival)
Eckert et al 2019[55]	Retrospective	NR (115)	FA/ Max & mand/1 piece	MZ (NR)	Ti- cylinders (Straumann)/NR	NR	NR	484 d (mean)	100	0	0
Chen & Pan 2019[56]	Retrospective	32 (32)	SC/Anterior & premolar/2 piece	Z (Cerec, Dentsply Sirona, Germany)	Ti-Base (Sirona Dental Systems)/NR	NR	NR	6 y	100	0	1 screw loosening 2 porcelain chipping 3 crown loosening 1 occlusal wear
Koenig et al 2019[27]	Prospective	NR (57)	44 SC/ Posterior 13 FDP/ Posterior (1 piece)	MZ (Lava Plus, 3 M)	Ti-base (1000er-Serie, Medentika, Germany)/ NR	Ti & Z: SB 50 µm Al2O3	-RelyX Ultimate -MHA	2 y	FDP 100 SC (NR)	4 (SC) 0 (FDP)	None
Weigl et al 2019[42]	RCT (split mouth)	22 (22)	SC/Posterior/ 1 piece	MZ (NR)	Ti-base (C abutment; Ankylos)/NR	NR	NR	1 y	100	0	1 screw loosening 2 loss of screw access filling
Bodereau et al 2020[64]	Prospective	10 (10)	SC/Max central incisor/1 piece	PVZ (Cercon® Dentsply Sirona)	Ti-Base (BioHorizons)/ 4.0 mm	Ti & Z: Single Bond Universal adhesive	RelyX Unicem	3.5 y (mean)	100	0	None
Menchini-Fabris et al 2020[57]	Retrospective	54 (54)	SC/ Anterior & premolar/1 piece	MLD (IPS e.max Press; Ivoclar)	Ti-base (NR)	NR	RelyX Unicem	3 y	100	0	None

De Angelis et al 2020[37]	Retrospective	38(38)	SC/ Posterior/ 1 piece	−19 MLD (IPS e. max Press; Ivoclar) -19 MZ (inCoris TZI; Dentsply Sirona)	Ti-Base (Dentsply Sirona)/NR	NR	MHA	3 y	100	0	1 minor chipping (MLD) 1 screw loosening (MZ)
Lerner et al 2020[28]	Retrospective	90(106)	SC/Posterior/ 2 piece	MZ (NR)	Ti-base (Multitech, Leone, Italy)/ Straight/ Angled/ 4.0 mm/6.0 mm	NR	Bifix SE	3 y	99	2	2 loss of "friction fit" connection between hybrid abutment and the fixture 2 de-cementations of crown from hybrid abutment
Mühlemann et al 2020[43]	RCT	38(38)	SC/Molar/1 piece	MZ (Lava Plus, 3M)	Ti-base (Variobase, RN)/ NR	-Ti: SB 50 µm Al2O3 (Rocatec) for 15s at 2.8 bar/ ethanol cleaning/ primer (Espe Sil) -Z: Ethanol cleaning/primer (Espe Sil)	MHA	1 y	100	0	None
Linkevicius et al 2021[44]	RCT	29(29)	SC/Posterior/ 1 piece	PVZ (NR)	Ti-base (MIS, V3)/NR	NR	NR	1 y	100	0	None
Wolfart et al 2021[45]	RCT	NR (27)	SC/Posterior/ 1 piece	MLD (IPS e.max CAD LT A16)	Ti-base (Camlog)/ 4.7 mm	-Ti: 50 µm Al2O3 SB at 2.0 bar / Monobond Plus -LD: HF etch for 20s and with silane for 60s/Monobond Plus	Multilink Implant	2 y	100	0	1 screw loosening
Vazouras et al 2022[46]	RCT	16 (16)	SC/Anterior & premolar /2 piece	Z (NR)	Ti-base (NR)	NR	Panavia F2	1 y	100	0	2 fracture of Z abutments at level of T-base
Bompolaki et al 2022[48]	Retrospective	NR (59)	SC/Anterior & posterior/1 piece	MLD (predilled ceramic block, Straumann AG)	Ti-base (Variobase)/NR	-Ti: No pretreatment -LD: 9% HF for 20s/ Monobo d Plus	MHA	18.4±4.8 mon (mean)	74.6 (biologic and technical complication free)	0	7 screw loosening 2 loss of screw access material

(*Continued*)

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Table 4 (Continued).

Study	Study Design	No. of Patients (Restorations) at End of Observation	Restoration Type	Ceramic Material Bonded to Ti-base	Ti-base Type/ Geometry/ ATTACHMENT Height	Surface Pre-Treatment	Luting Agent	Mean Follow up (Year or Month)	Overall Restoration Survival Rate (%)	Ti-Base Debond	Other Prosthetic Complications
Guncu et al 2022[58]	Retrospective	118 (182)	SC/Anterior & posterior/1 piece	MZ PVZ (Katana Zirconia HT, Kuraray)	Ti-base: (Variobase)/3.5, 5 mm	-Ti: SB 50 µm Al2O3 at 2 bar/ ultrasonic distilled water clean for 5 min -Z: SB 50 µm Al2O3 at 1 bar for 20s/ Monobond Plus	MHA	32 ±18 mon (mean)	98.9	0	1 Ti-base fracture 1 MZ fracture
Strauss et al 2022[59]	Prospective	22 (22)	SC/Anterior & premolar/1 piece	PVZ (Lava Plus)	Ti-base (Zirkon, Medentik)/ 3.5 mm (non-original)	NR	Panavia 21	5 y	81.8 (success rate)	0	3 minor chippings 1 major chipping 1 abutment loosening
Salem et al 2022[60]	Prospective	30 (30)	SC/Premolar/ 2 piece	MZ (Nacera pearl Q3)	Ti- base (Vitronex, FLOTECNO SRL)/4.0 mm	Ti & Z: steam-cleaned/ 50 µm Al2O3 SB at 2.5 bar for Ti and 1 bar for Z/ ultrasonic clean 99% isopropanol for 3min/ Monobond Plus	MHA	2 y	100	0	None
Happe et al 2022[31]	Retrospective	153 (199 implants supporting SC & 105 implants supporting FDPs)	−199 SC -(NR) FDP/ 2-piece	3Y-TZP (dima Mill Zirconia; Kulzer, Hanau)	-Camlog Ti-Base CAD/CAM; Camlog, -Medentika, (Hugelsheim) /NR	Ti & Z: SB & cleaning (NR)	Panavia 21	4.7 y (mean)	97.4 (Abutment survival rate)	0	17 ceramic chippings 6 abutment loosening 2 fractures of abutment
Al-Tarawneh et al 2023[35]	Retrospective	129 (173)	FA/Max & mand/1 piece	−72 MZ -101 PVZ (NR)	Ti-cylinders (NR)	NR	NR	1.9 y (mean)	100	8 events	9 ceramic chipping
Saponaro et a. 2023[29]	Retrospective	94 (153)	82 SC 51 FDP 20 FA 1 piece and 2 piece	Z (Zirkonzahn Prettau)	Ti-base (NR)	Ti & Z: SB 50 µm Al2O3 at 43.5 psi/ MKZ primer	Panavia F2	6 y (mean)	78.4 (success rate)	1(SC) 2 (FDP)	5.88%: fracture of veneering material 4.57%: prosthetic screw loosening

Strasding et al 2023[36]	RCT	54 (54)	SC/ Anterior & premolar/ 1 piece	−28 PVZ (Lava Plus, 3 M) -26 VLD (E.max CAD, Ivoclar)	Variobase (Straumann)/ NR	-Ti: SB 50 μm Al2O3/ ultrasonic bath/ Monobond Plus -LD: 5% HF for 20s -Z: SB 50 μm Al2O3	MHA	13.2 ± 2.4 mon (mean)	100	0	3 minor chipping (1 Z & 2 LD)
Gehrke et al 2023[61]	Retrospective	75 (109)	SC/Anterior & posterior/1 piece	CAD-CAM Ceramic (NR)	Ti-base (Implacil De Bortoli, São Paulo)/ 4.5mm	NR	NR	22.7 ± 6.2 mon (mean)	108/109 (surviving)	0	1 abutment fracture
Derksen & Wismeijer 2023[25]	RCT	50 (84)	41 SC 43 FDP/ Posterior/1 Piece	MZ (3M Lava Plus)	Ti-base: - (RN Variobase for Crown, 4.0 mm, Straumann) - (RN Variobase for Bridge/Bar, Straumann)/ NR	Ti: No pretreatment Z: SB ≤ 50μm Al2O3 at ≤ 2 bar	MHA	3 y	SC: 100 FDP: 97.7	1 (SC) 7 (FDP)	4 screw loosening 2 loss of occlusal screw access filling
Schubert et al 2024[62]	Retrospective	25 (40)	SC/Posterior/ 1 piece	LD (IPS e.max CAD, Ivoclar)	Ti- base CAD-CAM abutment/NR	NR	NR	5.9 ± 1.4 y (mean)	97.5	0	1 fractured crown
Beck et al 2024[26]	RCT	27 (27)	SC/posterior/ 1 piece	Z (ZerionR ML)	Ti- base (VariobaseR, CEREC)/NR	NR	NR	4.23 ± 1.10 y (mean)	100	2	1 fracture of Ti-base at neck
Graf et al 2024[30]	Retrospective	371 (601)	SC/Posterior/ 1 piece	−398 MLD -203 PVZ (NR)	Ti-base (NR)	NR	NR	6.4 ± 2.1 y (mean)	MLD: 93.5 PVZ: 95.5	8 (LD) 1.3% 0 (PVZ)	10 screw loosening 8 Loss of composite obturation 21 Fracture/chipping of ceramic
Smirani et al 2024[63]	Prospective	18 (18)	SC/Anterior & premolar/1 piece	Z (Lava Plus, 3 M)	Ti-base: Zirkon, Medentika Gmbh)/NR	NR	Panavia 21	7.5 y	94.4	0	2 major and 1 minor chippings

Abbreviations: NR., not reported; RCT, Randomized controlled trial; Ti-base, titanium base; Z, zirconia; MZ, monolithic zirconia; PVZ, porcelain veneered zirconia; MLD, monolithic lithium disilicate; LD, lithium disilicate; SC, single crown; FDP, fixed dental prosthesis; FA, full arch; SB, sandblasting; MHA, Multilink Hybrid Abutment; Max, maxillary; Mand, mandibular, 3Y-TZP, Yttria-stabilized tetragonal zirconia polycrystal.

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Table 5 Overview of the Utilized Resin Cements

Cement Name	Curing Mode	Manufacturer
Panavia F2	Dual-curing	Kuraray Noritake
Multilink Automix	Dual-curing	Ivoclar Vivadent
Variolink	Dual-curing	Ivoclar Vivadent
Multilink Hybrid Abutment (MHA)	Self-curing	Ivoclar Vivadent
RelyX Unicem	Self-curing	3M ESPE
LinkAce	Dual-curing	GC
Multilink Implant	Dual-curing	Ivoclar Vivadent
RelyX Ultimate	Dual-curing	3M ESPE
Bifix SE	Dual-curing	VOCO
Panavia 21	Dual-curing	Kuraray Noritake

ranging from 1 to 6 years. Saponaro et al[29] in their retrospective study reported 2 debonds between zirconia abutments and Ti-bases supporting FDPs, where one patient was a bruxer with a three-unit cantilevered prosthesis, and the other had a four-unit anterior prosthesis. The zirconia abutments were successfully rebonded to Ti-bases for the duration of the study, but the patient with the four-unit anterior prosthesis subsequently experienced major porcelain fracture in his veneered zirconia prosthesis.[29] In addition, a 3-year RCT[25] reported seven events (16.3%) of Ti-bases' debonding from two-implant supported zirconia FDPs in the first year of function. All Ti-bases except one were successfully re-bonded intraorally to zirconia FDPs for the duration of the study. The restoration that could not be re-bonded intraorally was due to mucosal overgrowth and it was sent to technician to re-bond it; however, it debonded again and considered as a failure.[25]

Full-Arch Prostheses

Twelve clinical studies reported on prosthetic outcomes of 2861 zirconia full-arch screw-retained prostheses. While eight publications did not report on any incidence of debonding, four retrospective studies revealed 17 events of debonding from 2447 assessed prostheses.[32–35] All de-bonded titanium bases/cylinders were successfully re-bonded to zirconia prostheses either intraorally or in the laboratory for the duration of the studies.

Restorative Material

Regarding the effect of ceramic restorative material on the bond stability, Strasding et al[36] in their RCT showed that lithium disilicate and zirconia crowns bonded to Ti-bases performed comparably without any debonding event at 1-year follow-up.[36] De Angelis et al[37] in their cross-sectional retrospective study also revealed analogous clinical outcomes for both zirconia and lithium disilicate crowns bonded to Ti-bases without any debonding event after a 3-year follow-up. On the other hand, Graf et al[30] evaluated retrospectively the clinical performance of monolithic lithium disilicate crowns and veneered zirconia crowns luted to Ti-bases through a mean follow-up of 6 years. The study showed no significant differences in survival rate, significantly lower prosthetic complications for lithium disilicate crowns; however, more debonding events for lithium disilicate crowns over the observation period (8 debonds of 398 lithium disilicate crowns, 0 debond of 203 zirconia crowns).[30]

Risk of Bias in Studies

Twelve RCTs[25,26,36,38–46] were evaluated using the RoB 2 tool. For four RCTs,[38,42,44,46] the overall risk of bias was considered low, whereas the other 8 RCTs[25,26,36,39–41,43,45] presented some concerns due to risk of bias in some domains as presented in Table 6. Two non-randomized controlled studies[47,48] were evaluated using the ROBINS-I tool and showed a serious risk of bias as presented in Table 7. All 26 one-arm non-controlled clinical studies[27–35,37,49–64] were evaluated using the Joanna Briggs Institute's critical appraisal tool and were found to have a low[27–31,35,37,52,54–56,59–62,64] to moderate risk of bias[32–34,49–51,53,57,58,63] as presented in Table 8.

Table 6 Risk of Bias Domains for Randomized Controlled Trials (RCTs)

Study	D1	D2	D3	D4	D5	Overall
Erhan Çömlekoğlu et al 2018[38]	+	+	+	+	+	+
Cheng et al 2019[39]	-	+	+	+	+	-
Mangano & Veronesi 2018[40]	+	+	+	-	+	-
Joda et al 2018[41]	+	+	+	-	+	-
Weigl et al 2019[42]	+	+	+	+	+	+
Mühlemann et al 2020[43]	+	-	+	+	+	-
Linkevicius et al 2021[44]	+	+	+	+	+	+
Wolfart et al 2021[45]	+	+	+	-	+	-
Vazouras et al 2022[46]	+	+	+	+	+	+
Strasding et al 2023[36]	+	+	+	-	+	-
Derksen & Wismeijer 2023[25]	+	+	+	-	+	-
Beck et al 2024[26]	+	+	+	-	+	-

Notes: D1: Bias arising from the randomization process D2: Bias due to deviations from intended interventions D3: Bias due to missing outcome data D4: Bias in measurement of the outcome D5: Bias in selection of the reported result X high - some concerns + low.

Table 7 Risk of Bias Domains for Non-Randomized Clinical Trials

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Caramês et al 2019[47]	X	+	+	●	X	-	-	X
Bompolaki et al 2022[48]	X	X	+	+	-	-	+	X

Notes: D1: Bias due to confounding D2: Bias in selection of participants into the study D3: Bias in classification of interventions D4: Bias due to deviations from intended interventions D5: Bias due to missing data D6: Bias in measurement of outcomes D7: Bias in selection of the reported result X serious - moderate + low ● no information.

Table 8 Risk of Bias Check List for One-Arm Non-Controlled Clinical Studies

Study	1	2	3	4	5	6	7	8	9	10	Overall Risk
Limmer et. al 2014[49]	+	+	+	-	-	+	+	+	-	+	Moderate
Carames et al 2015[50]	-	-	+	-	-	+	+	+	+	-	Moderate
Venezia et al 2015[51]	-	-	+	+	+	-	+	+	-	+	Moderate
Box et al 2018[52]	-	+	+	+	+	+	+	+	+	+	Low

(*Continued*)

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Table 8 (Continued).

Study	1	2	3	4	5	6	7	8	9	10	Overall Risk
Gonzalez & Triplett 2017[32]	-	+	+	-	-	+	+	+	+	+	Moderate
Vizcaya 2018[53]	-	+	+	-	-	+	-	+	+	+	Moderate
Bidra et al 2018[33]	-	-	+	+	+	-	-	-	+	+	Moderate
Tischler et al 2018[34]	-	+	+	+	-	-	+	+	-	+	Moderate
Linkevicius et al 2018[54]	+	+	+	-	-	+	+	+	+	+	Low
Eckert et al 2019[55]	-	+	+	+	+	+	+	+	-	+	Low
Chen & Pan[56]	+	-	+	+	-	+	+	+	+	+	Low
Koenig et al 2019[27]	+	+	+	+	-	+	+	+	+	+	Low
Menchini-Fabris et al 202[57]	+	-	+	+	-	+	-	+	-	+	Moderate
De Angelis et al 2020[37]	+	+	+	+	+	+	+	+	+	+	Low
Lerner et al 2020[28]	+	+	+	+	-	+	+	+	-	+	Low
Guncu et al 2022[58]	+	+	+	-	-	+	+	+	-	+	MODERATE
Strauss et al 2022[59]	+	+	+	+	-	+	+	+	+	+	Low
Salem et al 2022[60]	+	+	+	+	+	+	+	+	+	+	Low
Happe et al 2022[31]	+	+	+	+	-	+	+	+	-	+	Low
Al-Tarawneh et al 2023[35]	+	+	+	+	-	-	+	+	+	+	Low
Saponaro et a 2023[29]	+	+	+	+	-	+	+	+	+	+	Low
Gehrke et al 2023[61]	+	+	+	+	-	+	+	+	+	+	Low
Schubert et al 2024[62]	+	+	+	+	+	+	+	+	+	+	Low
Graf et al 2024[30]	+	+	+	+	+	+	+	+	+	+	Low
Smirani et al 2024[63]	+	+	+	-	-	+	+	+	-	+	Moderate
Bodereau et al 2020[64]	+	-	+	+	-	+	+	+	+	+	Low

Notes: 1 Were there clear criteria for inclusion in the case series? 2.Was the condition measured in a standard, reliable way for all participants included in the case series? 3 Were valid methods used for identification of the condition for all participants included in the case series? 4 Did the case series have consecutive inclusion of participants? 4 Did the case series have complete inclusion of participants? 5 Was there clear reporting of the demographics of the participants in the study? 6 Was there clear reporting of clinical information of the participants? 7 Were the outcomes or follow-up results of cases clearly reported? 8 Was there clear reporting of the presenting sites'/clinics' demographic information? 9 Was statistical analysis appropriate? X no 1–4 (yes): high risk - unclear 5–7 (yes): moderate risk + yes 8–10 (yes): low risk ● no information.

Discussion

The rapid advancement of digital technologies and the introduction of new ceramic materials that offer superior mechanical and esthetic qualities, have largely attributed to the notable transition from metal-ceramic to all-ceramic CAD-CAM implant restorations bonded to Ti-bases.[4,9]

This systematic review aimed to review all clinical studies reporting on the bond stability and durability between implant-supported fixed CAD-CAM ceramic restorations and Ti-bases.

In this review, 18 debonding events from Ti-bases of 2,056 (0.88%) assessed single ceramic copings,[25–30] 9 debondings of approximately 159 assessed multi-unit zirconia FDPs,[25,29,31] and 17 debondings of 2861 (0.59%) assessed full-arch zirconia prostheses,[32–35] were reported during observation periods ranging from 1 to 7.5. The reason why full-arch prostheses revealed the least reported debonding rate might be due to the delay in the visible clinical debonding of the prosthesis since it might remain stabilized on some bases even though some are detached. Another cause might be due to better distribution of forces on cross-arch splinted implants and copings compared with single crown.

Although low debonding rates were recorded for different types of restorations, this result should be interpreted with caution since these reported ultimate debonding events were usually preceded by micromovements that could not be detected clinically. Some debonds also might not be visible for multi-unit prostheses except after most of the Ti-bases debonded. These undetected micromovements or debonds might lead to several technical and biological complications. Therefore, the number of these debonds should be taken seriously with addressing the probable underlying causes for each one.

With regard to the effect of Ti-base height and geometry on bond stability, Graf et al[30] who reported eight events (1.3%) of debonding between lithium disilicate crowns and Ti-bases through the 6-year observation period, blamed the short height of the used Ti-bases as a possible cause of this complication. Furthermore, Gonzalez and Triplett,[32] who reported two events of debonding of the 44, investigated full-arch zirconia prostheses through a mean follow-up of 33 months, attributed the non-use of manufacturer's recommended Ti-bases and the inadequate height of the excessively reduced bases as possible causes. Another 3-year RCT[25] that reported seven events (16.3%) of Ti-bases' debonding from zirconia bridges in the first year of function, attributed the use of non-retentive, flat-cone Ti-bases as one of the possible causes. According to a recent systematic review of in vitro studies,[18] the height of the Ti-base was cited as a significant factor for ceramic/Ti-base bonding stability. Although the critical height for Ti-bases was not specified in this review, a recent systematic review[18] based on in vitro studies demonstrated that the critical height is approximately 3.5 mm, this can vary based on the Ti-base's design and the inclusion of micro or macro-retentive elements. It seems from the limited clinical evidence that Ti-base heights and geometries could affect the bond stability over time since short and non-retentive, flat-cone Ti-bases lead to more debonding events. However, further clinical investigations are needed.

Considering the impact of ceramic restorative material on ceramic/Ti-base bond stability, Strasding et al[36] in their RCT and De Angelis et al[37] in their retrospective study showed that lithium disilicate and zirconia crowns bonded to Ti-bases performed comparably without any debonding event at 1-year and 3-year follow-up, respectively. On the other hand, Graf et al[30] in their retrospective study reported eight events (1.3%) of debonding for lithium disilicate crowns (8 of 398), while no debonding event was recorded for zirconia crowns (0 of 203) through 6-year mean observation period. Nonetheless, the authors attributed this complication to the short height of Ti-bases used in the study rather than to the type of restorative material.[30] However, an in vitro study showed that zirconia crowns had inferior bonding capability to Ti-bases compared with lithium disilicate after thermo-mechanical aging.[15] This might be due to almost chemical inertness of the highly crystalline structure and to the lack of a glass phase of zirconia.[84] Due to controversy in the results, additional clinical investigations about the association between restorative material and the ceramic/Ti-base bonding stability might be conducted.

Regarding the micromechanical and/or chemical surface pre-treatments of ceramic and titanium, the reported surfaces' pre-treatment of zirconia and Ti-bases in this review ranged from no pre-treatment to air abrasion with 50µm alumina particles at 1- to 2.5-bar pressure with or without a priori primer application. Lithium disilicate bonding surfaces were usually etched with hydrofluoric acid and silanized prior to bonding. A recent systematic review based on in vitro studies[18] suggests that air-abrasion of the bonding surfaces of zirconia and Ti-bases using alumina particles of 45–50µm is the most effective method to enhance the retentive strength. Additionally, in vitro studies[13,17] demonstrated that the use of bonding systems comprising MDP-based primers and the application of universal primers before cementation appeared to be advantageous for sandblasted Ti-bases. Although most of the identified clinical studies showed favorable bond stability between ceramic restorations and Ti-bases with the reported surface pretreatment, it remains difficult to draw a conclusion on the most effective surface pre-treatment method. Given the limited clinical evidence on this topic, further research is needed.

If the utilized bonding system could affect the bond stability, Koenig et al 2019[27] reported that the four debonds (5.3%) that occurred between zirconia crowns and Ti-bases during the 2-year observation period, were encountered only with crowns luted with dual-cure resin cement (RelyX Ultimate). However, they were successfully re-bonded with self-cure resin cement (Multilink Hybrid Abutment) for the duration of the study.[27] In addition, Saponaro et al,[29] who reported 2 occurrences of debonding between zirconia abutments and Ti-bases for multi-unit FDPs and one debond for single restoration, advocated the use of self-cure resin cement rather than the initially used dual-cure resin cement (Panavia F2). Furthermore, Gonzalez & Triplett,[32] who reported two events of debonding of the 44 investigated full-arch zirconia prostheses through the 33-month observation period, considered that one of the factors that might contribute to debonding was the use of dual-cure resin cement that was inadequately polymerized under the zirconia prostheses. It appears from the limited clinical evidence that self-cure resin cement offers a more stable bond between zirconia restorations and Ti-bases over time; however, no recommendation can be given for the best luting agent, and further clinical research is needed.

In addition, biomechanical prosthesis- and patient-related factors might contribute to prosthetic complications like debonding of restorations from Ti-bases. Saponaro et al[29] reported 2 occurrences of debonding between zirconia abutments and Ti-bases in multi-unit FDPs and another debonding was for single crown. One patient was a bruxer with a three-unit cantilevered prosthesis, another had a four-unit anterior prosthesis, and the other was a bruxer. The authors attributed these complications partly to biomechanical patient- and prosthesis-related factors.[29] Inadequacy of passive fit is another factor that could affect the bond stability, as reported in a 3-year RCT,[25] where seven events (16.3%) of Ti-bases' debonding from zirconia FDPs were recorded in the first year of function. The authors attributed these debonds to the probable inadequacy of passive fit of these bridges and to the use of non-retentive, flat-cone Ti-bases.[25] Impassive fit is usually manifested as abutment screw loosening; however, the non-retentive design of Ti-bases makes them the weakest link in the system and thus de-cemented earlier.[25] It appears from the limited evidence that inadequacy of passive fit and biomechanical patient- and prosthesis-related factors could affect bond stability. However, further clinical investigations are required.

Although the current systematic review is a valuable addition to the current literature since it is the first review based on clinical studies that shed the light on this important topic, this review presents with some limitations. One of the limitations is that most of the included studies reported 1–5-year follow-up data; as such, the clinical data are still regarded short-term. In addition, the risk of bias in the included studies ranged from low to moderate, with two presented with serious risk of bias. A further limitation is the issue that a meta-analysis could not be implemented due to the relative heterogeneity of the data. Moreover, due to scarcity of clinical research reporting on bond stability, this review included studies even though the utilized bonding protocol was not specified. More well-designed clinical research assessing the impact of different "genuine" Ti-bases geometries, heights, cementation protocols, surface pre-treatments, restorative materials, and the interaction between these factors on bond stability, with long-term observation periods beyond 5 years, is highly advocated.

Conclusions

From the limited evidence available, this systematic review concluded that CAD-CAM implant-supported all-ceramic restorations bonded to Ti-bases demonstrated relatively high bond stability during observation periods ranging from 1 to 7.5 years; whereas full-arch zirconia prostheses revealed the least reported debonding rate (0.88%) compared with single ceramic copings and multi-unit zirconia FDPs, respectively. However, these results should be interpreted with caution since they represent the ultimate visible debonding events in the short-term evaluation. Although most of the identified studies showed favorable bond stability between ceramic restorations and Ti-bases with the reported surface pretreatment, it remains difficult to draw a conclusion on the most effective surface pre-treatment due to limited clinical evidence. It appears that ceramic restorative materials may affect bond stability; however, it remains difficult to draw conclusions on the behavior of different ceramic restorative materials due to controversy in the results. In addition, it seems that Ti-base heights and geometries could affect the ceramic restoration/Ti-base bond stability over time since short and non-retentive, flat-cone Ti-bases lead to more debonding events. It also appears that self-cure resin cement offers a more stable bond between zirconia restorations and Ti-bases over time; however, no recommendation can be given for the best luting agent, and further clinical studies are required. Lastly, inadequacy of passive fit and biomechanical patient- and prosthesis-related factors could affect the bond stability between implant ceramic restorations and Ti-bases.

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References

1. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res*. 2012;23(suppl 6):s2–s21. doi:10.1111/j.1600-0501.2012.02547.x
2. Remísio MJDS, Borges T, Castro F, Gehrke SA, Fernandes JCH, Fernandes GVO. Histologic osseointegration level comparing titanium and zirconia dental implants: meta-analysis of preclinical studies. *Int J Oral Maxillofac Implants*. 2023;38(4):667–680. doi:10.11607/jomi.10142
3. Sailer I, Mühlemann S, Kohal RJ, et al. Reconstructive aspects: summary and consensus statements of group 3The 5th EAO consensus conference 2018. *Clin Oral Implants Res*. 2018;29(suppl 18):s237–s242. doi:10.1111/clr.13302
4. Vozzo LM, Azevedo L, Fernandes JCH, et al. The success and complications of complete-arch implant-supported fixed monolithic zirconia restorations: a systematic review. *Prosthesis*. 2023;5(2):425–436. doi:10.3390/prosthesis5020029
5. Guilardi LF, Pereira G, Giordani JC, Kleverlaan CJ, Valandro LF, Rippe MP. Cement choice and the fatigue performance of monolithic zirconia restorations. *Oper Dent*. 2022;47:461–472. doi:10.2341/20-143-L
6. Bonyatpour M, Giti R, Erfanian B. Implant angulation and fracture resistance of one-piece screw-retained hybrid monolithic zirconia ceramic restorations. *PLoS One*. 2023;18:e0280816. doi:10.1371/journal.pone.0280816
7. Alseddiek A, Al-Zordk W, Attia A. Retention of hybrid-abutment-crowns with offset implant placement: influence of Crown materials and Ti-base height. *BMC Oral Health*. 2023;23(1):784. doi:10.1186/s12903-023-03490-1
8. Al-Thobity AM. Titanium base abutments in implant prosthodontics: a literature review. *Eur J Dent*. 2022;16(1):49–55. doi:10.1055/s-0041-1735423
9. Chantler JGM, Evans CDJ, Zitzmann NU, Derksen W. Clinical performance of single implant prostheses restored using titanium base abutments: a systematic review and meta-analysis. *Clin Oral Implants Res*. 2023;34(Suppl 26):64–85. doi:10.1111/clr.14128
10. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. *BMC Oral Health*. 2017;17:124. doi:10.1186/s12903-017-0415-0
11. Sen N, Us YO. Fatigue survival and failure resistance of titanium versus zirconia implant abutments with various connection designs. *J Prosthet Dent*. 2019;122(3):315.e1–315.e7. doi:10.1016/j.prosdent.2019.05.036
12. 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. doi:10.1111/clr.13395
13. Zahoui A, Bergamo ET, Marun MM, Silva KP, Coelho PG, Bonfante EA. Cementation protocol for bonding zirconia crowns to titanium base CAD/CAM Abutments. *Int J Prosthodont*. 2020;33(5):527–535. doi:10.11607/ijp.6696
14. Al-Tarawneh S, Thalji G, Cooper L. Full-arch implant-supported monolithic zirconia fixed dental prostheses: an updated systematic review. *Int J Oral Implantol*. 14(1):13–22.
15. Pitta J, Hjerppe J, Burkhardt F, Fehmer V, Mojon P, Sailer I. Mechanical stability and technical outcomes of monolithic CAD/CAM fabricated abutment-crowns supported by titanium bases: an in vitro study. *Clin Oral Implants Res*. 2021;32(2):222–232. doi:10.1111/clr.13693
16. Chen CJ, Papaspyridakos P, Guze K, Singh M, Weber HP, Gallucci GO. Effect of misfit of cement-retained implant single crowns on crestal bone changes. *Int J Prosthodont*. 2013;26(2):135–137. doi:10.11607/ijp.3137
17. Bergamo TP, Zahoui E, A LAI, et al. Retention of zirconia crowns to Ti-base abutments: effect of luting protocol, abutment treatment and autoclave sterilization. *J Prosthodont Res*. 65(2):171–175. doi:10.2186/jpr.JPOR_2019_537
18. Ntovas P, Ladia O, Pachiou A, Fehmer V, Sailer I. In vitro assessment of cementation of CAD/CAM fabricated prostheses over titanium bases. A systematic review. *Clin Oral Implants Res*. 2024;35(10):1203–1225. doi:10.1111/clr.14347
19. Fogel DB. Factors associated with clinical trials that fail and opportunities for improving the likelihood of success: a review. *Contemp Clin Trials Commun*. 2018;11:156–164. doi:10.1016/j.conctc.2018.08.001
20. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi:10.1136/bmj.n71
21. Schardt C, Adams MB, Owens T, Keitz S, Fontelo P. Utilization of the PICO framework to improve searching PubMed for clinical questions. *BMC Med Inform Decis Mak*. 2007;7:16. doi:16",1,0,0>10.1186/1472-6947-7-16

22. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:l4898. PMID:31462531. doi:10.1136/bmj.l4898
23. Sterne JAC, Hernan MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355: i4919. PMID:27733354. doi:10.1136/bmj.i4919
24. Munn Z, Barker TH, Moola S, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. *JBI Evid Synth*. 2020;18:2127–2133. doi:10.11124/JBISRIR-D-19-00099
25. Derksen W, Wismeijer D. Three-year follow-up of a randomized clinical trial on screw-retained monolithic zirconia restorations on ti-base abutments based on digital or conventional impression techniques. *Int J Prosthodont*. 2023;36(4):410–415. doi:10.11607/ijp.7891
26. Beck F, Zupancic Cepic L, Lettner S, et al. Clinical and radiographic outcomes of single implant-supported zirconia crowns following a digital and conventional workflow: four-year follow-up of a randomized controlled clinical trial. *J Clin Med*. 2024;13(2):432. doi:10.3390/jcm13020432
27. Koenig V, Wulfman C, Bekaert S, et al. Corrigendum to "clinical behavior of second-generation zirconia monolithic posterior restorations: two-year results of a prospective study with Ex Vivo analyses including patients with clinical signs of bruxism. *J Dent*. 2019;91:103229. doi:10.1016/j.jdent.2021.103694
28. Lerner H, Mouhyi J, Admakin O, Mangano F. Artificial intelligence in fixed implant prosthodontics: a retrospective study of 106 implant-supported monolithic zirconia crowns inserted in the posterior jaws of 90 patients. *BMC Oral Health*. 2020;20(1):80. doi:10.1186/s12903-020-1062-4
29. Saponaro PC, Karasan D, Donmez MB, Johnston WM, Yilmaz B. Prosthetic complications with monolithic or micro-veneered implant-supported zirconia single-unit, multiple-unit, and complete-arch prostheses on titanium base abutments: a single center retrospective study with mean follow-up period of 72.35 months. *Clin Implant Dent Relat Res*. 2023;25(1):99–106. doi:10.1111/cid.13149
30. Graf T, Lyko A, Dahmer I, et al. Clinical performance and risk factors of all-ceramic screw-retained implant crowns in the posterior region based on a retrospective investigation. *Clin Oral Implants Res*. 2024;35(7):685–693. doi:10.1111/clr.14264
31. Happe A, von Glasser GS, Neugebauer J, et al. Clinical performance of zirconia implant abutments luted to a titanium base - a retrospective cross-sectional study. *Int J Comput Dent*. 2022;25(1):37–45.
32. Gonzalez J, Triplett RG. Complications and clinical considerations of the implant-retained zirconia complete-arch prosthesis with various opposing dentitions. *Int J Oral Maxillofac Implants*. 2017;32(4):864–869. doi:10.11607/jomi.5369
33. Bidra AS, Tischler M, Patch C. Survival of 2039 complete arch fixed implant-supported zirconia prostheses: a retrospective study. *J Prosthet Dent*. 2018;119(2):220–224. doi:10.1016/j.prosdent.2017.05.004
34. Tischler M, Patch C, Bidra AS. Rehabilitation of edentulous jaws with zirconia complete-arch fixed implant-supported prostheses: an up to 4-year retrospective clinical study. *J Prosthet Dent*. 2018;120(2):204–209. doi:10.1016/j.prosdent.2017.12.010
35. Al-Tarawneh S, Thalji G, Shonberg D, Fayz L, Cooper L. Retrospective cohort evaluation of full-arch zirconia implant-supported fixed prostheses. *Int J Oral Maxillofac Implants*. 2023;38(2):381–390. doi:10.11607/jomi.10022
36. Strasding M, Hicklin SP, Todorovic A, Fehmer V, Mojon P, Sailer I. A multicenter randomized controlled clinical pilot study of buccally micro-veneered lithium-disilicate and zirconia crowns supported by titanium base abutments: 1-year outcomes. *Clin Oral Implants Res*. 2023;34 (1):56–65. doi:10.1111/clr.14018
37. De Angelis P, Passarelli PC, Gasparini G, Boniello R, D"Amato G, De Angelis S. Monolithic CAD-CAM lithium disilicate versus monolithic CAD-CAM zirconia for single implant-supported posterior crowns using a digital workflow: a 3-year cross-sectional retrospective study. *J Prosthet Dent*. 2020;123(2):252–256. doi:10.1016/j.prosdent.2018.11.016
38. Çömlekoğlu M E, Nizam N, Çömlekoğlu MD. Immediate definitive individualized abutments reduce peri-implant bone loss: a randomized controlled split-mouth study on 16 patients. *Clin Oral Investig*. 2018;22(1):475–486. doi:10.1007/s00784-017-2136-9
39. Cheng CW, Chien CH, Chen CJ, Papaspyridakos P. Randomized controlled clinical trial to compare posterior implant-supported modified monolithic zirconia and metal-ceramic single crowns: one-year results. *J Prosthodont*. 2019;28(1):15–21. doi:10.1111/jopr.12767
40. Mangano F, Veronesi G. Digital versus analog procedures for the prosthetic restoration of single implants: a randomized controlled trial with 1 year of follow-up. *Biomed Res Int*. 2018;2018:5325032. doi:10.1155/2018/5325032
41. Joda T, Ferrari M, Bragger U, Zitzmann NU. Patient Reported Outcome Measures (PROMs) of posterior single-implant crowns using digital workflows: a randomized controlled trial with a three-year follow-up. *Clin Oral Implants Res*. 2018;29(9):954–961. doi:10.1111/clr.13360
42. Weigl P, Saarepera K, Hinrikus K, Wu Y, Trimpou G, Lorenz J. Screw-retained monolithic zirconia vs. cemented porcelain-fused-to-metal implant crowns: a prospective randomized clinical trial in split-mouth design. *Clin Oral Investig*. 2019;23(3):1067–1075. doi:10.1007/s00784-018-2531-x
43. Mühlemann S, Lakha T, Jung RE, Hämmerle CHF, Benic GI. Prosthetic outcomes and clinical performance of CAD-CAM monolithic zirconia versus porcelain-fused-to-metal implant crowns in the molar region: 1-year results of a RCT. *Clin Oral Implants Res*. 2020;31(9):856–864. doi:10.1111/clr.13631
44. Linkevicius T, Linkevicius R, Gineviciute E, Alkimavicius J, Mazeikiene A, Linkeviciene L. The influence of new immediate tissue level abutment on crestal bone stability of subcrestally placed implants: a 1-year randomized controlled clinical trial. *Clin Implant Dent Relat Res*. 2021;23 (2):259–269. doi:10.1111/cid.12979
45. Wolfart S, Rittich A, Groß K, et al. Cemented versus screw-retained posterior implant-supported single crowns: a 24-month randomized controlled clinical trial. *Clin Oral Implants Res*. 2021;32(12):1484–1495. doi:10.1111/clr.13849
46. Vazouras K, Gholami H, Margvelashvili-Malament M, Kim YJ, Finkelman M, Weber HP. An esthetic evaluation of different abutment materials in the anterior maxilla: a randomized controlled clinical trial using a crossover design. *J Prosthodont*. 2022;31(8):673–680. doi:10.1111/jopr.13520
47. Caramês J, Marques D, Malta Barbosa J, Moreira A, Crispim P, Chen A. Full-arch implant-supported rehabilitations: a prospective study comparing porcelain-veneered zirconia frameworks to monolithic zirconia. *Clin Oral Implants Res*. 2019;30(1):68–78. doi:10.1111/clr.13393
48. Bompolaki D, Punj A, Fellows C, Truong C, Ferracane JL. Clinical Performance of CAD/CAM monolithic lithium disilicate implant-supported single crowns using solid or predrilled blocks in a fully digital workflow: a retrospective cohort study with up to 33 months of follow up. *J Prosthodont*. 2022;31(1):38–44. doi:10.1111/jopr.13364
49. Limmer B, Sanders AE, Reside G, Cooper LF. Complications and patient-centered outcomes with an implant-supported monolithic zirconia fixed dental prosthesis: 1 year results. *J Prosthodont*. 2014;23(4):267–275. doi:10.1111/jopr
50. Carames J, Tovar Suinaga L, Yu YC, Pérez A, Kang M. Clinical advantages and limitations of monolithic zirconia restorations full arch implant supported reconstruction: case series. *Int J Dent*. 2015;2015:392496. doi:10.1155/2015/392496

51. Venezia P, Torsello F, Cavalcanti R, D"Amato S. Retrospective analysis of 26 complete-arch implant-supported monolithic zirconia prostheses with feldspathic porcelain veneering limited to the facial surface. *J Prosthet Dent*. 2015;114(4):506–512. doi:10.1016/j.prosdent.2015.02.010
52. Box VH, Sukotjo C, Knoernschild KL, Campbell SD, Afshari FS. Patient-reported and clinical outcomes of implant-supported fixed complete dental prostheses: a comparison of metal-acrylic, milled zirconia, and retrievable crown prostheses. *J Oral Implantol*. 2018;44(1):51–61. doi:10.1563/aaid-joi-D-17-00184
53. Rojas Vizcaya F. Retrospective 2- to 7-year follow-up study of 20 double full-arch implant-supported monolithic zirconia fixed prostheses: measurements and recommendations for optimal design. *J Prosthodont*. 2018;27(6):501–508. doi:10.1111/jopr.12528
54. Linkevicius T, Linkevicius R, Alkimavicius J, Linkeviciene L, Andrijauskas P, Puisys A. Influence of titanium base, lithium disilicate restoration and vertical soft tissue thickness on bone stability around triangular-shaped implants: a prospective clinical trial. *Clin Oral Implants Res*. 2018;29(7):716–724. doi:10.1111/clr.13263
55. Eckert SE, Hueler G, Sandler N, Elkattah R, McNeil DC. Immediately Loaded Fixed full-arch implant-retained prosthesis: clinical analysis when using a moderate insertion torque. *Int J Oral Maxillofac Implants*. 2019;34(3):737–744. doi:10.11607/jomi.7193
56. Chen JY, Pan YH. Zirconia implant abutments supporting single all-ceramic crowns in anterior and premolar regions: a six-year retrospective study. *Biomed J*. 2019;42(5):358–364. doi:10.1016/j.bj.2019.05.001
57. Menchini-Fabris GB, Crespi R, Toti P, Crespi G, Rubino L, Covani U. A 3-year retrospective study of fresh socket implants: CAD/CAM customized healing abutment vs cover screws. *Int J Comput Dent*. 2020;23(2):109–117.
58. Guncu MB, Aktas G, Guncu GN, Anıl D, Turkyilmaz I, Antonoff LR. Clinical, technical, and radiologic outcomes of 182 implant-supported zirconia single crowns using titanium-base abutments: a retrospective study. *Int J Prosthodont*. 2022;35(4):553–559. doi:10.11607/ijp.7796
59. Strauss FJ, Siegenthaler M, Hämmerle CHF, Sailer I, Jung RE, Thoma DS. Restorative angle of zirconia restorations cemented on non-original titanium bases influences the initial marginal bone loss: 5-year results of a prospective cohort study. *Clin Oral Implants Res*. 2022;33(7):745–756. doi:10.1111/clr.13954
60. Salem MT, El-Layeh M, El-Farag SAA, Salem AS, Attia A. Clinical assessment of different implant-supported esthetic crown systems fabricated with semi-digital workflow: two-year prospective study. *J Esthet Restor Dent*. 2022;34(8):1247–1262. doi:10.1111/jerd.12961
61. Gehrke SA, Scarano A, Cortellari GC, Fernandes GVO, Mesquita AMM, Bianchini MA. Marginal bone level and biomechanical behavior of titanium-indexed abutment base of conical connection used for single ceramic crowns on Morse-taper implant: a clinical retrospective study. *J Funct Biomater*. 2023;14(3):128. doi:10.3390/jfb14030128
62. Schubert O, Goob J, Schweiger J, Güth JF, Edelhoff D, Graf T. Clinical performance of monolithic lithium disilicate hybrid abutment crowns over at least 3.5 years. *J Prosthodont*. 2024;33(1):34–40. doi:10.1111/jopr.13719
63. Smirani R, Chantler JG, Endres J, et al. Clinical outcomes of single implant supported crowns utilising the titanium base abutment: a 7.5-year prospective cohort study. *J Dent*. 2024;149:105306. doi:10.1016/j.jdent.2024.105306
64. Bodereau EF, Flores VY, Naldini P, Torassa D, Tortolini P. Clinical evaluation of the nasopalatine canal in implant-prosthetic treatment: a pilot study. *Dent J*. 2020;8(2):30. doi:10.3390/dj8020030
65. Oliva J, Oliva X, Oliva JD. All-on-three delayed implant loading concept for the completely edentulous maxilla and mandible: a retrospective 5-year follow-up study. *Int J Oral Maxillofac Implants*. 2012;27(6):1584–1592.
66. Moscovitch M. Consecutive case series of monolithic and minimally veneered zirconia restorations on teeth and implants: up to 68 months. *Int J Periodontics Restorative Dent*. 2015;35(3):315–323. doi:10.11607/prd.2270
67. Larsson C, Vult von Steyern P. Ten-year follow-up of implant-supported all-ceramic fixed dental prostheses: a randomized, prospective clinical trial. *Int J Prosthodont*. 2016;29(1):31–34. doi:10.11607/ijp.4328
68. Joda T, Brägger U. Time-efficiency analysis of the treatment with monolithic implant crowns in a digital workflow: a randomized controlled trial. *Clin Oral Implants Res*. 2016;27(11):1401–1406. doi:10.1111/clr.12753
69. Lin YT, Shen YF, Wei PC, Hsu KW. Clinical evaluation of two-piece zirconia abutments with bonded titanium inserts for implant-supported restorations. *J Prosthet Dent*. 2020;123(3):449–454. doi:10.1016/j.prosdent.2019.01.006
70. Gierthmuehlen PC, Berger L, Spitznagel FA. Monolithic screw-retained lithium disilicate implant crowns: preliminary data of a prospective cohort study. *Int J Prosthodont*. 2020;33(3):272–276. doi:10.11607/ijp.6684
71. Linkevicius T, Puisys A, Linkevicius R, Alkimavicius J, Gineviciute E, Linkeviciene L. The influence of submerged healing abutment or subcrestal implant placement on soft tissue thickness and crestal bone stability. A 2-year randomized clinical trial. *Clin Implant Dent Relat Res*. 2020;22(4):497–506. doi:10.1111/cid.12903
72. Iglhaut G, Salomon S, Fretwurst T, et al. Cross-sectional evaluation of clinical and immunological parameters at partially microgrooved vs machined abutments in humans. *Int J Implant Dent*. 7(1):46. doi:10.1186/s40729-021-00329-8
73. Krawiec M, Hadzik J, Olchowy C, Dominiak M, Kubasiewicz-Ross P. Aesthetic outcomes of early occlusal loaded sla dental implants with hydroxyl ion modified surface-A 12 months prospective study. *Materials*. 14(21):6353. doi:10.3390/ma14216353
74. Mihali SG, Wang HL, Karancsi O, Bratu EA. internal hexagon vs conical implant-abutment connections: evaluation of 3-year post-loading outcomes. *J Oral Implantol*. 2021;47(6):485–490. doi:10.1563/aaid-joi-D-19-00160
75. Finelle G, Popelut A, Knafo B, Martín IS. Sealing Socket Abutments (SSAs) in molar immediate implants with a digitalized CAD/CAM protocol: soft tissue contour changes and radiographic outcomes after 2 years. *Int J Periodontics Restorative Dent*. 2021;41(2):235–244. doi:10.11607/prd.4579
76. Derksen W, Tahmaseb A, Wismeijer D. A randomized clinical trial comparing the clinical fit of CAD/CAM monolithic zirconia Fixed Dental Prostheses (FDP) on ti-base abutments based on digital or conventional impression techniques. one year follow-up. *Int J Prosthodont*. 2021;34(6):733–743. doi:10.11607/ijp.7074
77. Derksen W, Tahmaseb A, Wismeijer D. Randomized clinical trial comparing clinical adjustment times of CAD/CAM screw-retained posterior crowns on ti-base abutments created with digital or conventional impressions. One-year follow-up. *Clin Oral Implants Res*. 2021;32(8):962–970. doi:10.1111/clr.13790
78. Linkevicius T, Alkimavicius J, Linkevicius R, Gineviciute E, Linkeviciene L. Effect of ti-base abutment gingival height on maintenance of crestal bone in thick Biotype patients: a randomized clinical trial with 1-year follow-up. *Int J Oral Maxillofac Implants*. 2022;37(2):320–327. doi:10.11607/jomi.9406

79. Cakan U, Özcan M. Implant-supported extra-orally cemented monolithic zirconia crowns: a prospective controlled clinical study up to 18 months in function. *Eur J Prosthodont Restor Dent*. 2022;30(4):276–283. doi:10.1922/EJPRD_2029Cakan08
80. Khamis MM, Zakaria NH. Effect of screw access channel on the fracture rate of lithium disilicate cement-retained implant-supported posterior crowns. *J Prosthet Dent*. 2022;127(4):618–625. doi:10.1016/j.prosdent.2020.08.047
81. Farrag KM, Khamis MM. Effect of anodized titanium abutment collars on peri-implant soft tissue: a split-mouth clinical study. *J Prosthet Dent*. 2023;130(1):59–67. doi:10.1016/j.prosdent.2021.09.019
82. Naumann M, Scholz P, Krois J, Schwendicke F, Sterzenbach G, Happe A. Monolithic hybrid abutment crowns (screw-retained) versus monolithic hybrid abutments with adhesively cemented monolithic crowns. *Clin Oral Implants Res*. 2023;34(3):209–220. doi:10.1111/clr.14031
83. Gehrke P, Pietruska MJ, Korth A, et al. Cohort study evaluating clinical, technical, biological, and esthetic outcomes of implant supported zirconia single crowns cemented on titanium-base abutments: 7-year mean follow-up. *Int J Oral Maxillofac Implants*. 1–24. 10.11607/jomi.11039
84. Inokoshi M, De Munck J, Minakuchi S, Van Meerbeek B. Meta-analysis of bonding effectiveness to zirconia ceramics. *J Dent Res*. 2014;93:329–334. doi:10.1177/0022034514524228