REVIEW ARTICLE

Effect of Different Veneering Techniques on the Mechanical Failure of Tooth-supported Veneered Zirconia Crowns: A Systematic Review

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Abstract

Purpose: To assess the influence of different veneering techniques on the mechanical failure of tooth-supported veneered zirconia crowns.

Materials and methods: An electronic literature search of PubMed, MEDLINE, SCOPUS, and Web of Science databases for relevant publications up to December 2021 was performed using the following MeSH combinations: zirconia, veneers, layering, pressing, computer-assisted design-on (CAD-on), clinical, *in vitro*, and crown. The focus of this study was to determine which layering technique in a single zirconia crown has the least mechanical complications according to the well-established PICO strategy. Titles and abstracts were screened to select studies based on the set criteria.

Results: Of the 1,834 studies, 42 were selected for full-text reading and 12 of these met the inclusion criteria. All selected articles were *in vitro* studies. Among the veneering techniques, controversial findings were noted for pressed vs layered ceramic, whereas the CAD-on group showed significantly less chipping. The CAD-on technique using fused lithium disilicate layering ceramic exhibited superior mechanical performance with single crown-layered zirconia restorations over all other materials and techniques.

Conclusions: Veneering techniques influence the mechanical performance of tooth-supported veneered zirconia restorations, with the advantage of the CAD-on-fused lithium disilicate technique. The findings are mainly supported by *in vitro* studies on single-crown restorations. Nevertheless, the clinical evidence regarding which veneering technique has better performance was inconclusive, and it suggests that all methods were adequate for clinical use.

Keywords: Computer-assisted design-on, Crowns, Layering, Pressing, Systematic review, Veneering technique, Zirconia.

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Introduction

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is one of the strongest ceramic materials, characterized by its exceptional biocompatibility and excellent mechanical properties, though with lower translucency than natural teeth.[1,2] Thus, glass-ceramic materials have been used to veneer zirconia to improve its optical properties.[3]

The most commonly reported mechanical complications for bilayer Y-TZP restorations are chipping and delamination of the ceramic veneer layer.[4,5] A meta-analysis reviewing single crowns, reported 22.3% more chipping incidents in tooth-supported zirconia crowns compared to metal-ceramic.[6] These mechanical failures of veneered zirconia crowns, might be related to the propagation of micro-cracks caused by occlusal forces, wear, and material fatigue.[2,7] In addition, different factors including veneering technique and thickness, framework thickness and design, and ceramic firing and cooling protocols may also affect the clinical performance of veneered zirconia prostheses.[2,8–10]

To minimize the risk of veneering zirconia failure, attention has been given to different factors such as the veneering technique, anatomical design framework, and modulus of elasticity of both the framework and veneering layers.[11]

One of the factors influencing zirconia performance is the veneering technique used for the ceramic layer.[3] Three techniques are employed for this technique. The first technique is layering, which is traditionally applied manually to zirconia frameworks using a mixture of ceramic powder and liquid followed by firing cycles.[12] The second is pressing, where the veneering layer is waxed on the zirconia framework, burned out, and pressed with appropriate veneering ceramic material, assuming that the single, high-temperature, firing cycle would improve the homogeneity and mechanical properties of the veneering layer.[12,13] The third one is CAD-on, computer-aided design (CAD)/computer-aided manufacturing (CAM) systems that are recently being utilized to

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design and mill both the zirconia framework and the veneering ceramic layer, later joined either by a sintered glass-ceramic layer or by a resin cement.[14–17]

The purpose of this systematic review was to compile the current information about veneering techniques and their influence on the mechanical failure of tooth-supported veneered-zirconia crowns. The null hypothesis was that there would be no significant difference in the failure rate between layering, pressing, and CAD-on veneering techniques for zirconia crowns.

Materials and Methods

Focused Topic and Patient, Intervention, Comparison, Outcome (PICO) Questions

The focus of this study was to determine which layering technique in a single zirconia crown has the least mechanical complications according to the well-established PICO strategy, 2009. (1) Population: *in vitro* tooth-supported single crown veneered zirconia. (2) Intervention: veneering techniques (pressed and CAD-on). (3) Control group: layering technique for veneering zirconia. (4) Outcome: mechanical failure of veneering techniques. The focus of the present review was "which veneering technique showed the lowest mechanical failures of tooth-supported veneered-zirconia crowns amongst the available studies?"

Search Strategy and Selection Criteria

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[16] Comprehensive search strategies were established to identify studies published before December 2021. Published studies were searched in the electronic literature databases of the US National Library of Medicine, PubMed, and Web of Science. The databases were searched for articles published in peer-reviewed journals using MeSH terms, keywords, and other free terms; and Boolean operators (OR, AND) were used to combine the searches. The key terms "Zirconia," "Crown," "Veneer," "Porcelain," "Ceramic," and "Clinical study" were combined with "Veneering Technique," "Pressed Ceramic," "Layered ceramic," "CAD-on," "CAD/CAM," "Fracture," and "Chipping."

The electronic search was supplemented by manual searching for the last 10 years through the following journals: *Dental Materials*, *Journal of Esthetic and Restorative Dentistry*, *Journal of Prosthetic Dentistry*, *Journal of Prosthodontics*, *International Journal of Prosthodontics*, *International Journal of Periodontics and Restorative Dentistry*, and *Quintessence International*, *Journal of Oral Rehabilitation*. In addition, the references of the selected articles were reviewed for possible inclusion.

The exclusion criteria were as follows: articles that evaluated one veneering technique, fixed partial denture, implant crown; full-arch implant-supported prosthesis was also excluded due to design complexity. To represent a more clinical situation, studies with non-anatomical designs and static loading were excluded. All titles revealed by the strategy were independently filtered by two authors (SA and HA), and an abstract search was conducted to identify further relevant articles. Full-text articles were then retrieved and reviewed by the same authors if the abstracts were insufficient for screening.

Data extraction was as follows: authors, publication year, compared groups, sample size, veneering ceramics, heat treatment protocol, mechanical test, opposing dentition/material, outcome, and results. Data were extracted independently by two reviewers (SZ and WA) using a data-extraction form. Disagreements regarding data extraction were resolved by consensus between the two reviewers (SZ and WA).

The eligibility criteria for study selection were as follows: *in vitro* studies that met the following criteria were included: compared at least two of the three veneering techniques, evaluated mechanical outcomes, used anatomical sample configuration, and incorporated chewing simulation and cyclic loading to mimic the oral environment.

Qualitative assessment: Calibration between evaluators was performed and Cohen's kappa was determined. The chosen cut-off point was 85%. Quality assessment was performed by assessing the risk of bias based on parameters adapted from previous studies on basic research publications.[18] The criteria checklist included: (1) Published in a peer-reviewed journal. (2) Has complete statistical reporting. (3) Randomization of treatment or controls. (4) Blinded analysis. (5) Sample size calculation prior to the experiment. (6) Investigation of a dose-response relationship. (7) Statement of compliance with regulatory requirements. (8) Objective alignment between the study in question and the analysis. The quality level ranged between low, moderate, and high risk of bias based on reporting the parameters or not, and it reflected our confidence that the estimation of the effect was correct. A 6–8 positive decision was considered low risk of bias, whereas a 3–5 positive decision was considered moderate risk of bias. A 1–2 positive decision was considered high risk of bias.

Results

According to the PRISMA statement, a flowchart of the study selection process is depicted in Flowchart 1. A total of 1,834 studies were retrieved from electronic and manual searches, and 1,423 studies remained after the exclusion of duplicates. Following title and abstract screening, 1381 studies were excluded, and only 42 were available for full-text analysis. On evaluation, 30 studies[1,10,11,14,19–44] that did not fulfill the inclusion criteria were excluded. The specific reasons for the exclusion of these studies were as follows: 17 used static loading, seven used non-anatomical design, and six evaluated fixed partial denture (Table 1).

The included 12 studies[12,15,45–54] had an *in vitro* design and were published between 2011 and 2021. The distribution of these studies was as follows: two compared pressing and layering techniques, six compared layering techniques and CAD-on, and four compared all three techniques (pressing, layering, and CAD-on). When the articles investigated different aspects, only samples or tests that matched the inclusion criteria were included. The use of artificial aging to apply repetitive stresses on the adhesion proved to negatively impact the loading-bearing capacity.[17] To minimize the heterogeneity, selected studies were divided into two groups based on the use of artificial aging. A summary of the included studies is presented in Tables 2 and 3. Table 4 includes the quality assessment of the risk of bias based on parameters adapted from previous studies on basic research publication by Mikolajewicz et al.[18]

From the included studies, inconsistent core and veneering thicknesses were noted; the thickness range of the zirconia framework was 0.5–1 mm and 0.4–2 mm. The CAD-on technique generally showed higher fracture resistance than the layered or pressing techniques. However, a study found no significant difference in the overall performance between the layered ceramic and CAD-on groups.[51] Connecting the milled veneering material

Flowchart 1: Flowchart summarizing the studies selected

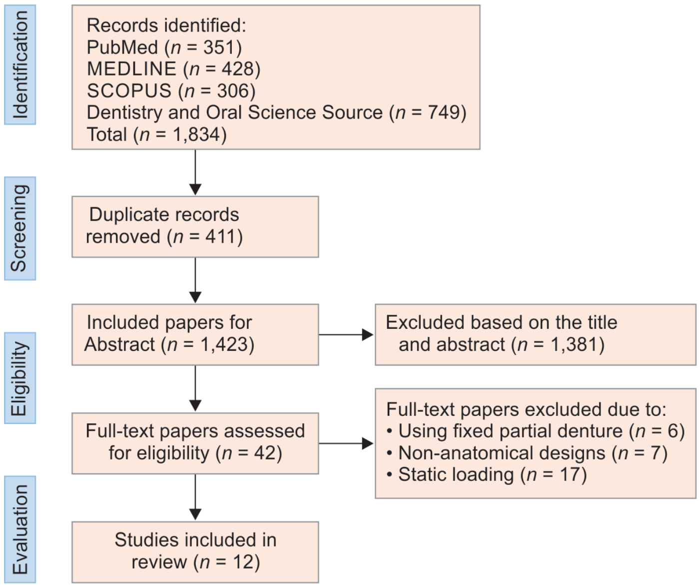

Table 1: Excluded studies

Study	*Compared groups*	*Reason for exclusion*
Oh et al.[19]	P & L	Nonanatomical sample
Lin et al.[20]	P & L	Nonanatomical sample
Jang et al.[21]	P & L	Nonanatomical sample
Guess et al.[22]	P & L	Nonanatomical samples
Alessandretti et al.[23]	L & CAD-on	Nonanatomical sample
Tsalouchou et al.[24]	P & L	Nonanatomical sample
Kumchai et al.[25]	P, L, & CAD-on	Nonanatomical sample
Gungor et al.[26]	P, L, & CAD-on	4-unit FDPs
Mahmood et al.[1]	P, L, & CAD-on	3-unit FDPs
Chaar et al.[27]	P & L	3-unit FDPs
Grohmann et al.[28]	L & CAD-on	3-unit FDPs
Naenni et al.[29]	P & L	3-unit FDPs
Christensen and Ploeger[30]	P & L	3-unit FDPs
Stawarczyk et al.[31]	P & L	Static loading
Aboushelib et al.[32]	P & L	Static loading
Turk et al.[33]	P & L	Static loading
Eisenburger et al.[34]	P & L	Static loading
Ansong et al.[35]	P & L	Static loading
Ishibe et al.[36]	P & L	Static loading
Vidotti et al.[37]	P & L	Static loading
Subash et al.[38]	P & L	Static loading
Pharr et al.[39]	P, L, & CAD-on	Static loading
Kanat et al.[14]	P, L, & CAD-on	Static loading
Choi et al.[40]	P, L, & CAD-on	Static loading
de Cassia et al.[41]	P & L	Static loading
Kanat-Erturk et al.[11]	P, L, & CAD-on	Static loading
Beuer et al.[42]	P, L, & CAD-on	Static loading
Brijawi et al.[43]	P & L	Static loading
Al-Wahadni et al.[44]	P, L, & CAD-on	Static loading
Mainjot et al.[10]	P, L	Static loading

P, pressed; L, layered; FDP, fixed dental prostheses

to the zirconia core is performed by cementation: using low-fusing glass ceramic. This study has documented that using low-fusing glass to connect two milled parts has a higher fracture resistance than cementation.[49] In addition, lithium disilicate milled veneer material has a higher resistance to fracture than feldspathic milled veneer.[49]

In layering veneer techniques, slow cooling after layering shows a higher fracture resistance than fast cooling.[49] A study reported a significantly lower fracture load with a pressed ceramic compared to a layered ceramic within the same manufacturer.[12] Furthermore, they observed more chippings with pressed ceramics and more total fractures with layered ceramics.

While comparing the CAD-on and layering techniques, one report analyzed the mode of failure and found that layered ceramic crowns had cohesive fractures only, compared to the CAD-on group, which had catastrophic failures, including the zirconia framework.[45] With regard to the effect of cyclic loading, it has been documented that crowns veneered with CAD-on feldspathic or lithium disilicate porcelain material did not fail with aging, whereas almost all manually veneered crowns failed below one-tenth of the chewing simulation cycles.[15,46] Most of the layered and pressed ceramic group failures were cohesive veneer fractures.

Discussion

This systematic review investigated the effect of veneering techniques on the mechanical performance of tooth-supported single-crown veneered zirconia restorations, both *in vitro* and *in vivo*. However, owing to the lack of clinical studies on this topic, the results were limited to laboratory studies.

Excessive veneer thickness or insufficient support from the framework increases the chance of mechanical complications, regardless of the veneering technique.[51] No significant difference in the overall performance between the layered ceramic and CAD-on groups was reported. This study had the lowest veneering thickness (0.4 mm) among all studies. A thin ceramic layer supported by an anatomical framework allows stress to be transmitted from the weaker ceramic layer to the stronger framework.

Table 2: Summary of included studies that used artificial aging

Author and publication year	*Compared groups*	*Sample size*	*Diesmaterial*	*Zirconia framework material*	*Core thickness (mm)*	*Veneering material*	*Veneering thickness (mm)*	*Heat treatment protocol*	*Load in (N)CyclesOpposing*	*Outcome*
Stawarczyk et al.[12]	P & L	*N* = 120 *P* = 60 *L* = 60	Cr-Co	ZENO TEC Wieland Dental	0.8–1.1	L: Zirox, GC initial ZR, Vita VM9, IPS e.max P: PressX Zr, GC Initial IQ LF, Vita PM9, IPS e.max ZirPress	1.6	Layered: multiple firing cycles according to manufacturers. Pressed: pressed using lost wax technique and quick or long heating methods using the manufacturers' parameters followed by glazing and firing	49 120,000 Composite	Chippings were more with pressed Fracture was more with the layered group
Beuer et al.[45]	L & CAD-on	*N* = 24 *L* = 12 CAD-on = 12	Metal	Zeno 4820 Premium, IMES, Eiterfeld, Germany	0.5	L: nano-fluorapatite-glass-ceramic (IPS e.max Ceram, IV) Liner (IPS e.max, ZirLiner, IV) CAD-on: IPS e.max CAD	0.7–1	Layered: IPS e.max was fired at 750°C. With a final firing/glazing CAD-on: fusion/crystallization firing in a conventional ceramic furnace at 850°C	49 120,000 SS	Layered zirconia crowns showed significantly less load-bearing capacity compared to the CAD-on group Layered group showed cohesive fractures without substructure failure. CAD-on group had catastrophic failures, including zirconia coping
Schmitter et al.[46]	L & CAD-on	*N* = 16 *L* = 8 CAD-on = 8	Co-Cr-Mo	Sirona inCoris ZI, mono L F1	0.6	L: feldspathic ceramic CAD-ON: lithium disilicate ceramics (IPS e.max CAD, cf) Fusion ceramic (IPS e.max CAD Crystall/Connect) between the framework and the CAD-on	2	Layered: two bonder firings, two dentine firings, and one glaze firing. CAD-on: fusion/crystallization firing, followed by glazing firing	108 1200,000 SS	During artificial aging: all CAD-on survive; 7 of the 8 layered failed All conventionally layered veneers which failed during chewing simulation with pure cohesive failures
Schmitter et al.[15]	L & CAD-on	*N* = 16 *L* = 8 CAD-on = 8	Co-Cr-Mo	Sirona inCoris ZI, mono L F1	0.6	L: feldspathic porcelain CAD-on: milled feldspathic CEREC Bloc. And cemented to core with Panavia 2.0 (Kuraray)	2	Layered: 5 firings at 900°C CAD-on: 1 glazing firing	108 1200,000 SS	No CAD-on failures, all layered failed after one-tenth of chewing simulation
Preis et al.[47]	L, P, & CAD-on	*N* = 12 *L* = 4 *P* = 4 CAD-on = 4	PMMA	Lava, 3M Espe	0.5	L: Lava Ceram P: IPS e.max Zirpress CAD-on: experimental material (glass-ceramic 3M ESPE) Connected to the core with fusion porcelain	0.5–1	Slow cooling with layered technique as a separate group, cooling phase was prolonged to 6 minutes	50 1200,000 Co-Cr alloy veneered with porcelain	Aging showed failures of all CAD-on but no failure with the pressed group No significant difference between groups in terms of the area and number of chippings

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Author and publication year	*Compared groups*	*Sample size*	*Diesmaterial*	*Zirconia framework material*	*Core thickness (mm)*	*Veneering material*	*Veneering thickness (mm)*	*Heat treatment protocol*	*Load in (N) Cycles Opposing*	*Outcome*
Schubert et al.[48]	L, P, & CAD-on	*N* = 60 *L* = 30 *P* = 10 CAD-on = 20	Titanium	Lava Frame, Shade FS3, 3M ESPE	0.5–0.6	L: BeCe Press Z Individual, Enamel 2, IPS e.max Ceram Dentin P: IPS e.max Press, fused to the framework with low fusing glass-ceramic CAD-on: LAVA DVS glass-ceramic block fused to the framework with Lava DVS fusion porcelain D4 3M ESPE, IPS e.max CAD fused to the framework with IPS e.max CAD Crystall/Connect, IPS e.max CAD fused to the framework with premixed fusion ceramic (Glaslot, biodentis GmbH)	0.7–0.8	CAD-on: DVS fusion/ crystallization firing, glazing. IC veneer crystallization firing, separate fusion firing, glazing Pressed: invested & heat pressed, bonding firing with low fusing glass-ceramic, and glazing Layered: glaze firing of layered ceramic	50 1200,000 SS	None of the specimens failed during artificial aging No statistically significant difference in fracture load values between the groups
Bankoglu Gungor and Karakoca Nemli[49]	L, P, & CAD-on	*N* = 60 *L* = 10 *P* = 10 CAD-on = 40	Composite	Incoris TZI	NA	L: Zr: Vita VM9 P: IPS e.max Press CAD-on Fused: IPS e.max CAD fused with IPS e.max CAD Crystall/Connect CAD-on Cemented: Cerec blocks, IPS e.max CAD, Lava Ultimate using Panavia F 2.0	NA	No details mentioned	50 1200,000 Co-Cr alloy veneered with porcelain	Fracture resistance: fused lithium disilicates CAD-on > cemented lithium disilicates CAD-on > cemented feldspathic CAD-on > pressed lithium disilicates > layered zirconia

P, pressed; L, layered; PMMMA, polymethylmethacrylate; Co, cobalt, Cr, chromium; MO, molybdenum; SS = stainless steel

Table 3: Summary of included studies that did not use artificial aging

Author and publication year	*Compared groups*	*Sample size*	*Abutment*	*Zirconia framework material*	*Core thickness (mm)*	*Veneering ceramics*	*Veneering thickness (mm)*	*Heat treatment protocol*	*Load in (N)CyclesOpposing*	*Study outcome*
Guess et al.[50]	P & L	$N = 42$ $L = 21$ $P = 21$	Composite	VITA In-Ceram YZ, Vita Zahnfabrik, Bad Säckingen, Germany	0.5	L: Vita VM9 P: Vita PM9	1	Glazing with the standard cooling procedure was applied as a final treatment	50–650 140,000 Tungsten carbide	Cohesive veneering fractures happen in both groups
Baladhandayutham et al.[51]	L & CAD-on	$N = 16$ $L = 8$ CAD-on = 8	Composite	LAVA; 3M ESPE	0.8	L: LAVA Ceram veneering porcelain CAD-on: LAVA DVS; 3M ESPE	0.4	L: firing for 4 min at 840°C after modifier, for 6 minutes at 810°C after initial dentin, 6 minutes for 800°C after second dentin and enamel, and for 2 minutes at 750°C after glazing CAD-on: fusion at 770°C for 4 minutes under vacuum. Glazing, firing for 2 minutes at 75°C	25 200,000 Steatite	No significant difference between the two veneered groups
Riedel et al.[52]	L & CAD-on	$N = 48$ per group $L = 32$ CAD-on = 16	Composite	Vita Zahnfabrik, Bad S€ackingen, Germany	0.7	L: leucite-reinforced glass (VM9: Vita) CAD-on: feldspathic-reinforced aluminosilicate glass (Vitablocs) cement with RelyX Unicem (Automix; 3M ESPE)	1.3–0.8	L: 16 crowns fast cooling after glazing 16 crowns rapid cooling	200 200,000 Steatite	Layering with rapid cooling showed fractures after a shorter testing period while slow cooling took longer to fracture CAD-on vita did not fracture but showed severe wear reaching the cement layer

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Author and publication year	*Compared groups*	*Sample size*	*Abutment*	*Zirconia framework material*	*Core thickness (mm)*	*Veneering ceramics*	*Veneering thickness (mm)*	*Heat treatment protocol*	*Load in (N) Cycles Opposing*	*Study outcome*
Alsarani et al.[53]	L, P, & CAD-on	$N = 30$ $L = 10$ $P = 10$ CAD-on = 10	Epoxy resin	IPS e.max ZirCAD	0.5	L: IPS e.max Ceram P: IPS e.max ZirPress CAD-on: IPS e.max CAD fused to zirconia with IPS e.max CAD Crystal/Connect	1	No details mentioned	50–450 500,000 NA	CAD on group survived cyclic loading without failure All layered and pressed crowns failed during cyclic loading and low chipping resistance Cohesive failure within the veneering porcelain was frequently observed Core/veneer interface separation was observed in two-layered samples
Pandurangan et al.[54]	L & CAD-On	$N = 20$ $L = 10$ CAD-on = 10	Epoxy resin	No mention of the manufacturer	0.5	L: Cercon Ceram Kiss (Dentsply®, USA) CAD-on: IPS e.max CAD (lithium disilicate) block A2 shade LT (low translucency) 14 mm (length) (Ivoclar Vivadent, Schaan, Liechtenstein, 40 ·m cement space thickness	1	For zirconia coping sintering temperature was maintained at 1540°C for a duration of 3 hours L: after layered applied firing at 850°C. The furnace Programat P300 (Ivoclar Vivadent, Schaan, Liechtenstein) was used for firing the veneering porcelain CAD-on: crystal/connect The firing is done at 840°C and then glazing at 810°C	50–250 250,000 NA	In hand-layered zirconia crowns, eight samples showed fracture on the veneering porcelain whereas two samples showed cracks on the veneering porcelain at around 180,000 cycles In contrast, eight samples showed no evidence of cracks and/or fractures on the veneering porcelain whereas only two samples of the CAD-on groups showed cracks on the veneering porcelain after about 220,000 cycles

P, pressed; L, layered; PMMMA, polymethylmethacrylate; Co, cobalt; Cr, chromium; MO, molybdenum; NA, not available

Table 4: Quality assessment of the risk of bias based on parameters adapted from previous studies on basic research publication by Mikolajewicz et al.[18]

Author	*Peer-reviewed*	*Randomization*	*Blindness*	*Sample size calculation*	*Dose-response relation*	*Statement of compliance with regulatory*	*Objective aligned with analysis*
Stawarczyk et al.[12]	+	+	–	–	–	+	+
Beuer et al.[45]	+	+	–	–	–	–	+
Schmitter et al.[46]	+	–	–	–	–	+	+
Schmitter et al.[15]	+	–	–	–	–	+	+
Preis et al.[47]	+	–	–	–	–	+	+
Schubert et al.[48]	+	–	–	–	–	+	+
Gungor et al.[49]	+	–	–	–	–	+	+
Alsarani et al.[53]	+	–	–	–	–	–	+
Pandurangan et al.[54]	+	–	–	–	–	+	+
Guess et al.[50]	+	–	–	–	–	–	+
Baladhandayutham et al.[51]	+	–	–	+	–	+	+
Riedel et al.[52]	+	+	–	–	–	+	+

+, Positive assessment; –, Negative assessment

In this systematic review, it was shown that the CAD-on veneering technique can be recommended as a reliable veneering technique in comparison to conventional layering or pressing. This technique provides multiple advantages, such as rendering of precise veneering thickness, eliminating the extensive labor work associated with layering and pressing techniques, and rapid production.

Layering techniques are prone to introducing voids, which act as the starting points for crack initiation. One of the advantages of this pressing technique is the production of homogenous and damage-resistant veneering. However, it has been evaluated that layered ceramics perform better than pressed ceramics.[12] One possible reason for this is the use of air abrasion to retrieve the pressed ceramic group, which might cause internal stresses leading to chipping and lower fracture loads compared with the layered ceramic group, which does not undergo air abrasion. A study emphasized that pressed ceramic performed better than layered ceramic and CAD-on groups during cyclic loading.[47] This finding might be related to the physical properties of the ceramic itself, as IPS e.max has a strength of ~100 MPa and fracture toughness of ~1 MPa $m^{1/2}$ values that exceed those of typical layered ceramics, such as Lava Ceram, as well as the glassy ceramic used with CAD-on design in the study.[47] On the contrary, it has been reported that the pressing technique did not provide either mechanical advantages or simplification of the veneering process or superior esthetic properties.[48] They found that adhesive veneer fractures occurred only with a particular group of veneering ceramics (infix), with both pressed ceramic and CAD-on groups. This could be attributed to the fact that the veneering technique in CAD-on involves full crystallization of the veneers first, followed by bonding to the framework with a separate bonding cycle instead of a combined crystallization/bonding firing cycle.

Veneering thickness is an important factor; as the veneer thickness increases, tensile stresses increases. The low thermal conductivity of zirconia results in a high-temperature difference and residual stresses between the framework and the veneering material.[55] Thus, slow cooling is recommended to reduce residual stresses.[56] The slow cooling protocol results in specimens requiring a greater number of cyclic loadings to fail than those prepared with a fast cooling protocol, which have a higher amount of residual tensile stresses locked inside the material during the cooling process.[47]

As previously shown, multiple factors affected the results of the included *in vitro* studies. Among these was the number of dynamic loading cycles and thermocycling, as part of the chewing simulation process. The current review documented that this ranged from 120,000 cycles for some studies[45,48] corresponding to only 6 months of function to up to 3.5 million cycles as documented in one study.[52] Most of the studies used 1,200,000 cycles, simulating 5 years of clinical use.[15,12,27,46,47] Researchers have found that humans have an average of 250,000 masticatory cycles per year.[57] Most of the reviewed studies had a loading frequency of 1–2 Hz, which is within the range reported in the literature as a chewing rate.[58–60] Only one study[53] had a high frequency of 20 Hz, which could be useful for decreasing testing time; however, it might affect the final outcomes.

There has been no information about lateral movements during chewing simulation except for two studies.[48,49] It has been recommended to include lateral movements in any *in vitro* studies evaluating the longevity of all-ceramic prostheses.[61,62] A separate table (Table 3) compiles studies that omitted thermocycling in the chewing simulation process[50–54] due to periodic tension and compression that occur at the crack tip as a result of thermocycling. This process is believed to further escalate the degree of damage.[63]

Another factor that could affect the standardization of these *in vitro* studies is the stump material used. Researchers have found that the fracture resistance of all-ceramic restorations depends on the modulus of elasticity of the abutment material.[64]

Moreover, it has been suggested that the distribution of stresses in a prosthesis cemented to dentin and composites of glass-fiber reinforced epoxy resin are similar, while it is different for other abutment materials such as steel or brass dies.[65] While majority of studies in the current review used metal stump,[15,12,45,47,52] others employed composite resin stumps,[18,49,51,62] PMMA abutments,[47] or epoxy resin.[50,53]

Finally, the opposing material, shape, and modulus of elasticity are essential factors that can affect the results of the mechanical testing of all-ceramic restorations.[66] Most of the reviewed studies used a ball-shaped indenter, except for three studies that used polished flat surfaces,[12] anatomical metal-ceramic crowns,[47] and cone-shaped indenters.[53] Studies have shown that the failure of the restoration is accelerated with a sharper indenter.[67] None of the studies used natural human teeth as opposing or abutment, which could have influenced the loading capacity of the specimens.[68]

In addition, eliminating the chipping of the veneering material has been attempted but not yet achieved. Clinicians might consider monolithic zirconia crowns, which require preservation of tooth structure, fewer fabrication defects, and less extensive labor compared to veneer zirconia-based restorations.

Conclusion

Evaluation of the influence of the three different veneering techniques of zirconia-based single crowns suggested that the CAD-on veneering technique had the lowest mechanical complications. An improvement was observed when the layering technique was combined with slow cooling. Clinical research with longer observation periods is required to draw clinical conclusions.

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