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Do thermal treatments affect the mechanical behavior of porcelain-veneered zirconia? A systematic review and meta-analysis.

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Abstract

Objectives.—A systematic review of *in vitro* studies was conducted to assess the effect of thermal treatments on flexural strength or critical load to failure of porcelain-veneered zirconia (PVZ).

Sources.—Literature searches were performed up to June 2018 in PubMed/MEDLINE, Scopus and Web of Science databases, with no publication year or language limits.

Data.—From 393 relevant studies, 21 were selected for full-text analysis, from which 7 failed to meet the inclusion criteria. The 14 remaining papers were included for the systematic review: 8 for meta-analysis and 6 restricted to descriptive analyses. Hand searching of reference lists resulted in no additional papers.

Study selection.—*In vitro* studies using PVZ specimens testing the influence of thermal treatments on the fracture resistance to monotonic or cyclic loading. Papers evaluating cooling rate were divided into those applying fast cooling from above the porcelain glass transition temperature (T_g), or from below it. Meta-analyses were performed separately for flexural strength and critical load to failure, using random effects at a 5% significance level.

Conclusions.—Delaying furnace opening at a temperature below the porcelain T_g is advised for PVZ restorations, in order to improve their fracture resistance. Additional information is required to confirm the apparently beneficial effect of self-glaze and repeated veneer firings on the mechanical properties of these restorations. Finally, in order to obtain conclusive and relevant evidence regarding thermal treatments and the fracture resistance of PVZs, future studies should concentrate on anatomically-correct crown specimens.

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Keywords

porcelain-veneered zirconia; cooling protocols; glaze firings; repeated firings; heat treatment; mechanical properties

1. Introduction

Yttria-stabilized tetragonal zirconia polycrystal ceramic has been perceived as a superior restorative material due to its biocompatibility and mechanical properties.[1] Porcelain-veneered zirconia restorations combine the strength of the zirconia framework with the excellent optical properties of the veneering porcelain.[2] The clinical survival rates of these restorations range from 90% to 95% in 5 years.[3–5] However, only about 70%,[6–7] did not require any intervention for continued function. Veneer fracture has been the leading cause of the reduced success rates.[6,7] These fractures may be repairable by polishing or filling with another restorative material (minor chipping) or not repairable (major chipping or catastrophic fractures), which lead to restoration replacement. Several factors have been associated to veneer failures, such as porcelain heterogeneous thickness,[8,9] non-anatomical design of the framework,[10–12] coefficient of thermal expansion (CTE) mismatch,[13] elastic modulus[14] and fracture toughness of porcelain,[15] inadequate veneer firing,[16] or residual thermal stresses.[17, 18]

Deleterious thermal stress gradients have been associated to the cooling rate after the last firing.[19,20] When the bilayer restoration is fast cooled, meaning the restoration is exposed to a thermal shock in high temperatures by immediately opening the furnace once the firing schedule is done, the surface of the porcelain solidifies and contract earlier, while the inner region remains at higher temperature. When the inner temperature decreases, the already solid surface hinders the contraction of the inner porcelain upon cooling, and residual tensile stresses become locked into the material system.[14,20] In contrary, when slow cooling is used, the restoration stays under controlled temperature reduction, thus, the whole structure of the restoration is expected to cool uniformly, effectively reducing residual thermal stresses.[21] However, not all previous studies have shown difference in the strength of bilayer systems after fast or slow cooling.[22–24] Various other thermal treatments have been proposed to overcome the chipping susceptibility and improve the fracture resistance of veneer ceramic, including glaze,[25] number of veneer firings,[26,27] and additional firing in different temperatures.[28] Previous studies suggest that these thermal treatments may relief thermal stresses.[29,30]

Considering that veneer chipping is a current clinical problem and it is strongly associated to the thermal treatments experienced by the porcelain veneered restoration, a systematic compilation of the contradictory literature and pooled data analysis may provide clear conclusions. Thus, this systematic review sought to assess the available scientific literature, investigating the following research question: How do thermal treatments (glaze, number of veneer firings, annealing, and cooling rate) influence the flexural strength or critical load to failure of porcelain-veneered zirconia?

2. Materials and methods

This systematic review was prepared and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[31] A non-registered protocol was elaborated prior to the literature search. The PICOS question was defined as follows: Population: porcelain-veneered zirconia (PVZ) specimens with any geometry; Intervention: slow cooling, more than two veneer firings, over- or self-glaze, or annealing; Comparison: fast cooling (from above or below transformation temperature (T_g) of the veneer porcelain), up to two veneer firings, no glaze, or no annealing; Outcomes: flexural strength or critical load to failure; Study design: *in vitro* studies.

2.1 Search Strategy

Literature search was carried out in PubMed/MEDLINE, Scopus and Web of Science databases to identify relevant articles up to June 2018. The search was conducted with no publication year or language limits. The studies were searched from PubMed/MEDLINE using the following strategy: ((zirconi*) OR (ytzp) OR (y-tzp)) AND ((dental porcelain*[MeSH Terms]) OR (porcelain) OR (veneer*) OR (bilayer) OR (veneered zirconia)) AND ((glaze*) OR (firing*) OR (fast cooling) OR (slow cooling) OR (cooling rate) OR (thermal treatment) OR (heat treatment) OR (annealing)) AND ((Compressive strength [MeSH Terms]) OR (strength) OR (flexural) OR (resistance) OR (load) OR (failure) OR (fatigue)). A sensitive search strategy was adapted for Scopus and Web of Sciences. The results of all databases searches were crosschecked to eliminate duplicates.

2.2 Selection of studies and eligibility criteria

Two reviewers (CSR and ILA) independently assessed the identified publications and selected them by title and abstract based on the following inclusion criteria: *in vitro* studies using PVZ specimens, which tested the influence of any thermal treatments on flexural strength or critical load to failure regardless the mechanical test configuration adopted (monotonic or cyclic loading).

The final decision about inclusion of a given study was made based on full-text evaluation of potentially relevant papers. Those which were not in accordance with the following criteria were excluded: 1) at least one intervention group subjected to more than two veneer firings, glaze firing, annealing, or slow cooling; 2) at least one comparison group subjected up to two veneer firings, no glaze, no annealing, or fast cooling, respectively; and 3) quantitative results reported as mean values and standard deviation (or equivalent central tendency and dispersion values) for flexural strength (MPa) or for critical load to failure (N), along with description of the sample sizes of each group. Reference lists of the included papers were also screened. When fatigue data was described in terms of reliability or number of cycles, authors were contacted and asked to provide the means and standard deviations of flexural strength or critical load to failure. Otherwise, these papers were not considered for meta-analyses. Any discrepancies between the reviewers were resolved through discussion and judgment by a third reviewer (LGM). The inter-examiner agreement (Kappa coefficient) was calculated for both phases (eligibility criteria: 0.86 and exclusion criteria: 0.95). Both reviewers also collected the data from the eligible studies independently, which were then compiled and discussed for consensus.

2.3 Risk of bias assessment

Quality of the studies was assessed by the two reviewers using the modified Consolidated Standards of Reporting Trials (CONSORT) checklist.[32] The following items were evaluated in each paper: 1) Structured summary of trial design, methods, results and conclusions, 2a) Scientific background and explanation of rationale, 2b) Specific objectives and/or hypothesis, 3) The intervention of each group, including how and when it was performed, with sufficient detail to enable replication, 4) Completely defined, pre-specified primary and secondary measured of outcome, including how and when they were assessed, 5) How the sample size was determined, 6) Method used to generate the random allocation sequence, 7) Mechanism used to implement the random allocation sequence, 8) Who assigned the random allocation, 9) Who was blinded after assignment to the intervention, 10) Statistical methods used to compare groups, 11) Results for each group and estimated size of effect and its precision, 12) Trial limitations, addressing sources of potential bias, imprecision, and, if relevant multiplicity of analysis, 13) Sources of funding and other support, 14) Where the full trial protocol can be accessed. Each parameter was judged as reported (Yes) or not reported (No).

2.4 Data analyses

Data analyses were carried out using Review Manager software version 5.3 (Cochrane Collaboration). Papers evaluating cooling rate were categorized into those which used a fast cooling (furnace opening and samples immediately removed) from above or below the T_g of the veneer porcelain. Distinct meta-analyses were performed using random effects for fast (aboveT_g) versus slow cooling, fast (belowT_g) versus slow cooling, and for flexural strength or critical load to failure data. Forest plots were created and significance level was set at 5% (Z test). The heterogeneity among studies was evaluated by Cochrane Q test, where $P<0.1$ was considered statistically significant, and the inconsistency I^2 test, where values higher than 50% were considered indicative of substantial heterogeneity. [33]

Studies that could not be included in meta-analyses due to lack of data (mean and standard deviation values and sample size) and/or due to methodological differences that did not allow comparisons with other studies, were only descriptively analyzed.

3. Results

3.1 Study selection

Figure 1 depicts a flowchart summarizing the selection process for studies. The search strategy identified 393 potentially relevant records. The first screening, by title and abstract, resulted in 21 studies that remained for full-text reading. Finally, 14 papers were included in the systematic review: 8 for quantitative evaluation using meta-analyses and 6 restricted to descriptive analyses. Manual searching through the reference lists of included studies resulted in no additional papers. Table 1 describes the characteristics of included studies.

The majority of studies evaluated cooling rate (10 studies),[13,22–24,36–41] two evaluated number of veneer firings,[26,27] one evaluated self-glaze,[25] and one investigated alternative firings.[28] The included studies used 9 different commercial brands of veneer porcelains, presenting a range of physical characteristics, such as elastic modulus (E), coefficient of thermal expansion (CTE) and glass transition temperature (T_g). These porcelains and their characteristics are described in Table 2.

3.2 Risk of bias

Table 3 presents the estimated risk of bias of each included study. All included papers properly presented a structured summary, specific objectives, and statistical analyses. Some papers reported to have performed randomization,[23,27,34,36,37] however, they have not reported how this procedure was carried out. Not one study clearly reported information about the mechanism used to implement the random allocation process, who performed it, and where the full trial protocol can be assessed. Background and rationale (6%), intervention description (19%), outcome description (12%), blinding (81%), limitations (56%), and funding resources (25%) were not always clearly reported.

3.3 Data analyses

Data analyses were performed qualitatively (descriptive summary) and quantitatively (meta-analyses), when appropriate, for each of the following treatments topics.

3.3.1 Cooling rate—Figure 1 shows the forest plot of the meta-analysis comprising 2 studies [34,37] with high heterogeneity (65%), comparing the fast cooling from below T_g versus slow cooling effect on PVZ flexural strength. As a result, no statistical difference was observed (P = 0.37) between cooling rates. A meta-analysis assessing the influence of fast cooling from above T_g versus slow cooling on flexural strength was carried out including 3 studies (Figure 2).[22,23,37] Heterogeneity was also considered high (61%) and no statistical difference was detected (P = 0.08). However, when the fast cooling from above T_g versus slow cooling effect on critical load to failure of PVZ crowns was investigated, the results of the meta-analysis involving 4 studies with low heterogeneity (33%)[13,35,38,39] showed that slow cooling yielded higher values of critical load to failure (P = 0.04) (Figure 3).

Paula et al.[36] investigated the influence of cooling rates on mechanical behavior of bilayer systems reporting only the number of cycles until failure. Thus, could not be included in meta-analyses, being only descriptively analyzed. The authors investigated the influence of fast cooling from above T_g and slow cooling rates on the survival of crown-shaped PVZ specimens. Their results showed that none of the fast cooled crowns survived 10^6 cycles, whereas all slow cooled crowns survived until the end of the test (10^6 cycles).

Another included study that was only descriptively analyzed was Meirelles et al.[24], which evaluated the effect of cooling regiments on flexural strength of different porcelains on bilayer samples. The slow cooling protocol adopted in this study is actually identical to the fast cooling from belowT_g, in which the samples were immediately removed from the furnace once the firing cycle ended. The comparison group was fast cooling from above T_g. The authors observed that the cooling protocols had no influence on flexural strength of the bar-shaped PVZ specimens.

3.3.2 Number of firings—

As only two methodologically distinct studies evaluated number of veneer firings, no meta-analyses could be performed. Vichi et al (2015)[27] observed that 2 and 5 veneering firings led to higher values of flexural strength [78 (13) MPa, and 78 (12) MPa, respectively] than only one firing cycle [52 (9) MPa], when tested with the porcelain veneer in tension. Lu et al (2011)[26] tested 2, 4, 6, 8 firing cycles and did not find any statistical difference among flexural strength means [996 (145) MPa, 999 (120) MPa, 1019 (51) MPa, and 1008 (103) MPa, respectively], tested with the zirconia layer in tension.

3.3.3 Glaze and annealing—

Only one included study compared groups with or without glaze firing.[25] The authors described that the load to failure of the polished and glazed group (389 ±202 N) was significantly greater than the polished-only group (301 ±199 N).

No included study evaluated annealing treatments, however Taskonak et al.[28] tested extended firing cycles comprising a 60 min holding time stage in different temperatures around the T_g, followed by slow or fast cooling. The authors reported that the treatments at or above the T_g followed by fast cooling resulted in higher flexural strength, compared to extended slow cooling to room temperature.

4. Discussion

The results of this systematic review showed that thermal treatments can influence flexural strength and critical load to failure of PVZ restorations. Most of included studies evaluated cooling protocols, which allowed us to perform three meta-analyses. For complex geometry samples (crowns), the cooling protocol significantly affected the critical load to failure of PVZ. However, when simple geometry samples (bars or discs) were used, no difference in fracture resistance was detected between different cooling regimens. Self-glaze and repeated veneer firings appeared to increase the mechanical strength of veneered systems based on the few studies available. However, this effect could only be descriptively analyzed, thus any inferences should be taken with caution.

A critical aspect regarding pooling data from various or multiple cooling rate studies is that there is no clear definition of what is considered slow cooling, since a large variety of protocols were used among the included studies (Table 1). Similarly, fast cooling regimens also vary among studies. Studies were classified into those where specimens were fast cooled from a temperature above the porcelain T_g or from below T_g, considering that the veneer porcelain behave completely different on each stage.[40] Glassy materials are viscous liquids above T_g, and fast cooling them from above this point means that structural contraction may lead to residual stress locked inside the material during the process.[13] In contrast, retarding fast cooling of PVZ restorations from temperatures below the T_g may impede the deleterious temperature gradients. Thus, avoiding the development of transient and residual stresses, which could weaken the ceramic material.[21] These observations are in agreement with the results of our meta-analysis, indicating that flexural strength is not affected by cooling rate when the rapid cooling stage is performed from below T_g. One should notice, though, that this meta-analysis pooled data from studies that used simple geometry specimens for the precise calculation of flexural strength. Finite element analysis (FEA) studies reported that cooling down restorations from 50˚C below T_g is enough to decrease residual stresses and avoid thermal gradients;[42] and that an overextended cooling protocol (closed furnace until 25˚C at 2˚C/min), besides time consuming, added more tensile and compressive residual stresses throughout the porcelain layer, compared to a more reasonable slow cooling regimen (closed furnace until 450˚C). [41]

Our two meta-analyses comparing fast cooling from above T_g versus slow cooling, for flexural strength (Fig. 2) and critical load to failure (Fig. 3), presented contradictory results. The studies evaluating flexural strength use simple geometry specimens, in which case no differences between the two cooling rates were observed. Nonetheless, when crown-shaped specimens were used and the critical load to failure was recorded, slow cooling yielded superior results. In addition to the geometric differences, bar and disc specimens (in the flexural strength analysis) had porcelain veneer thickness of 0.5 – 1.0 mm; while, the crown specimens (in the critical load to failure analysis) had 1.5 – 2.0 mm thick porcelain veneers. Benetti et al.[21], using FEA, observed that when porcelain layer increases from 1 to 2 mm, thermal stresses gradients increase throughout the veneer. The authors also observed that the fast cooling (furnace opening at 800˚C – above T_g) led to high levels of transient tensions, which were associated to internal microcracks and, consequently, early failures. Moreover, previous studies have observed distinct residual stresses in curved areas of PVZ crowns,[41–43] especially when fast cooling was applied.[43] Thus, it is plausible that the difference in residual stress distributions due to different geometries and thicknesses led to the contradictory meta-analyses results regarding flexural strength and critical load to failure.

The only two included studies that evaluated number of firings in PVZ indicate that two veneer firings may improve the flexural strength of the bilayer specimens, while no further improvement is seen when more than two firings are applied. However, these results must be interpreted with cautions, since one test was performed with porcelain in tension[27] and the other one with zirconia in tension.[26] Such contrast resulted in extremely different flexural strength values between the two papers, since the mechanical properties of the specimens are determined by the material under tension.[44] The study of Tang et al.[46], which is not included in this systematic review, also did not observe differences in the flexural strength of most monolithic veneering ceramics when fired for 2 up to 10 times. Nonetheless, other studies evaluating monolithic porcelain specimens, observed that increasing number of firings can improve hardness, density, and decrease porosity.[45,46]

Among the included studies, only one evaluated the effect of glaze firing on bilayer specimens.[25] The experimental groups included one that was just polished and another polished and self-glazed, which presented higher flexural strength. Self-glaze is technically convenient since it does not require the application of additional glazing material. This heat treatment aims to expose a glass-based material to temperatures at or above the T_g for 1 – 2 min in order to promote a superficial melting, improving gloss and healing surface deffects.[47] Previous literature is controversial, showing that self-glaze can either improve[48] or decrease[49] the flexural strength of monolithic porcelains, showing a lack of evidence regarding the effect of self- or over- glaze in mechanical properties of porcelains for bilayer systems.

Regarding annealing, not one study evaluating this heat treatment on PVZ met the inclusion criteria of this systematic review. Previous investigations have shown that annealing can promote crack healing[50] and improve flexural strength[51] of glassy ceramics. Nevertheless, annealing is very time consuming, firstly, the glassy material is heated and kept at a temperature above T_g for a given time, usually 10 h, to allow for atomic rearrangement; then, the material is slowly cooled in order to prevent new residual stresses.[40] The time issue is a practical disadvantage of annealing, which seems to discourage researchers to evaluate its effects on bilayer systems. Nonetheless, Taskonak et al.[28] studied extended firings at different temperatures around the T_g as an alternative thermal treatment. The authors tested four different additional firing cycles at temperatures below, at, and above porcelain T_g, followed by slow or fast cooling. They observed higher flexural strength for the groups treated at or above T_g then fast cooled. This may be associated with an atomic rearrangement, which only happens in temperatures above T_g, when the glass viscosity decreases.[40] Nonetheless, one should note that the authors compared fast cooling with an overextended slow cooling regimen (down to room temperature, taking around 600 min). An aforementioned FEA study[41] showed that overextended slow cooling below T_g is deleterious even for flat specimens.

Most papers in the literature do not clearly report the details of their methodological approaches. Similar shortcomings were also observed in the included studies (Table 3). Similarly, previous systematic reviews of *in vitro* studies also found only a few papers with low risk of bias,[52,53] which demonstrates that poor methodological report is a common problem.[54] Furthermore, most of the included studies tested cooling rates, while only very few, if any, investigated other thermal treatments. Thus, it was not possible to reach substantial conclusions on other treatments, such as glazing, annealing, and number of veneer firings. Another limitation relies on the heterogeneity of included studies, specially the lack of consensus about what is a slow or a fast cooling protocol. Interestingly, some manufacturers already recommend, for all firing cycles, that the furnace should only be opened below the porcelain T_g, which is in agreement with the findings of our systematic review. However, other manufacturers still disregard the deleterious effects of residual thermal stresses and recommend fast cooling from sintering temperature or any other firings (Table 2). In all included studies, compatible porcelains were used to veneer zirconia substructures, as recommended by the dental ceramic manufacturers (Table 2). Nonetheless, it is known that even small mismatches in CTE, along with the elastic properties of the porcelain, can affect the magnitude, location and type of residual stresses.[14] Moreover, other variables such as porcelain/zirconia thickness ratio[23,35] and the indenter used for load application[55,56] may also affect the results. Therefore, the high heterogeneity observed in our meta-analyses, may also be explained by the pooling of data including distinct porcelain/zirconia combinations and test configurations.

Despite all the methodological differences among the studies (Table 1), our results showed that fast cooling PVZ from temperatures above the porcelain T_g has deleterious effect on its critical load to failure for complex geometries -- crowns. However, delaying furnace opening to temperatures below the T_g, seems to be enough to preserve the material's mechanical behavior. In addition, the geometry of specimens for *in vitro* investigations of thermal stresses should be considered, since it seems to affect the mechanical response of veneered zirconia systems.

5. Conclusions

The systematic investigation of the literature has led to the recommendation to delay the furnace opening at a temperature below the porcelain glass transition temperature for porcelain-veneered zirconia restorations. This procedure improves the fracture resistance of the restoration, while fast cooling from temperatures above the porcelain glass transition temperature leads to a decrease in their critical load to failure. More studies are required to confirm the seemingly positive effect of self-glaze and repeated firings on the mechanical properties of these restorations. Nonetheless, future studies should concentrate on anatomically-correct crown specimens in order to obtain conclusive and relevant evidence regarding thermal treatments and the fracture resistance of PVZs.

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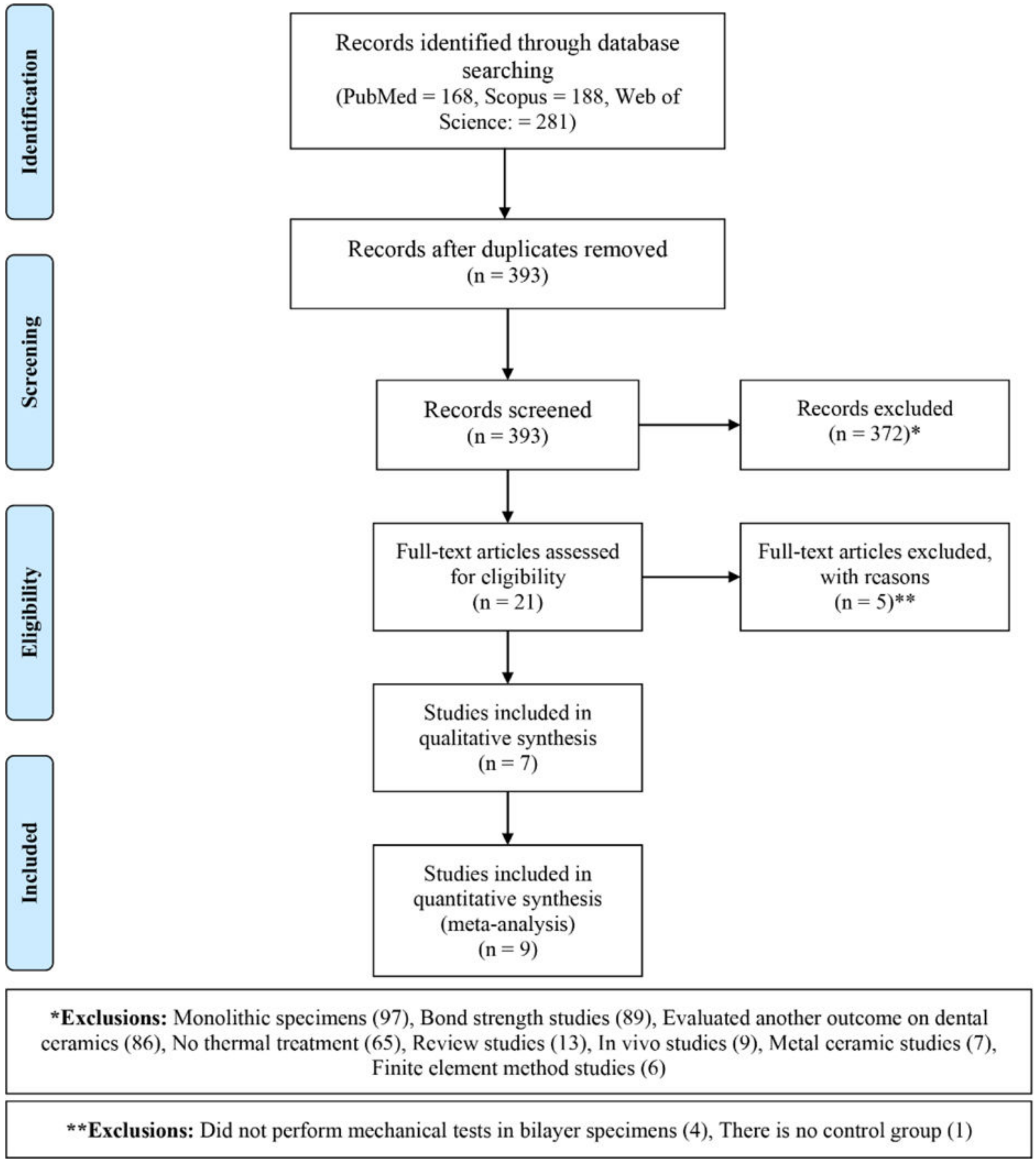

Figure 1.

Selection of studies procedures according to PRISMA

	Slow Cooling			Fast Cooling (Below Tg)				Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**	**Year**
Almeida Jr et al. 2013	50.4	11.8	30	52.3	9.5	30	65.9%	−1.90 [−7.32, 3.52]	2013
Passos et al. 2017	195.13	54.68	60	219.1	82.33	60	34.1%	−23.97 [−48.98, 1.04]	2017
Total (95% CI)			**90**			**90**	**100.0%**	**−9.42 [−29.92, 11.08]**	

Heterogeneity: $Tau^2 = 158.32$; $Chi^2 = 2.86$, df = 1 (P = 0.09); $I^2 = 65\%$
Test for overall effect: Z = 0.90 (P = 0.37)

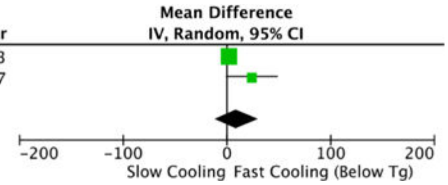

Figure 2.

Forest plot for flexural strength analysis of fast cooling (below Tg) versus slow cooling.

Study or Subgroup	Slow Cooling Mean	SD	Total	Fast Cooling (Above Tg) Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Almeida Jr et al. 2013	50.4	11.8	30	64.2	15	30	30.4%	−13.80 [−20.63, −6.97]	2013
Lima et al. 2013	59.23	14.29	32	61.65	14.6	32	29.8%	−2.42 [−9.50, 4.66]	2013
Longhini et al. 2016	201.02	52.96	30	209.54	51.04	30	6.2%	−8.52 [−34.84, 17.80]	2016
Meirelles et al. 2016	64.1	15.59	60	65.05	15.31	60	33.6%	−0.95 [−6.48, 4.58]	2016
Total (95% CI)			**152**			**152**	**100.0%**	**−5.76 [−12.88, 1.36]**	

Heterogeneity: $Tau^2 = 31.30$; $Chi^2 = 9.01$, df = 3 (P = 0.03); $I^2 = 67\%$
Test for overall effect: Z = 1.59 (P = 0.11)

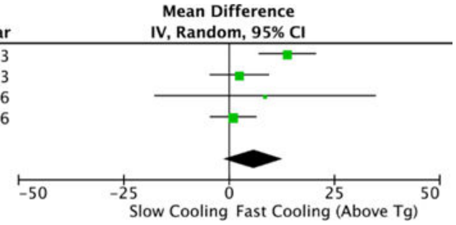

Figure 3.
Forest plot for flexural strength analysis of fast cooling (above Tg) versus slow cooling.

Study or Subgroup	Slow Cooling Mean	Slow Cooling SD	Slow Cooling Total	Fast Cooling (Above Tg) Mean	Fast Cooling (Above Tg) SD	Fast Cooling (Above Tg) Total	Weight	Mean Difference IV, Random, 95% CI	Year
Rues et al. 2010	641	155	10	481	178	10	46.7%	160.00 [13.71, 306.29]	2010
Belli et al. 2013	2,447.03	493.08	64	2,332.63	636.19	64	35.3%	114.40 [−82.80, 311.60]	2013
Preis et al. 2013	2,025.6	385.4	7	1,841.8	257.1	6	16.1%	183.80 [−168.10, 535.70]	2013
Tang et al. 2017	3,913.55	2,265.56	20	2,530.7	1,372.04	20	1.8%	1382.85 [222.06, 2543.64]	2017
Total (95% CI)			**101**			**100**	**100.0%**	**170.14 [11.16, 329.11]**	

Heterogeneity: $Tau^2 = 8511.74$; $Chi^2 = 4.49$, $df = 3$ ($P = 0.21$); $I^2 = 33\%$

Test for overall effect: $Z = 2.10$ ($P = 0.04$)

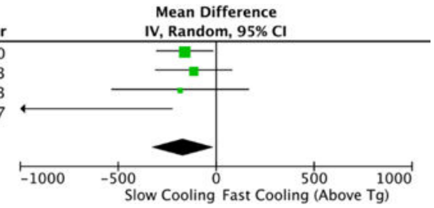

Figure 4.

Forest plot for critical load to failure analysis of fast cooling (above Tg) versus slow cooling.

Table 1.

Characteristics of included studies.

Author (year)	Materials	Intervention	Comparison	Last firing	Testing set up	Veneer thickness* (mm)	Sample size (n)
Ebadian et al (2018)	Vita PM9 (Vita) Vita In Ceram YZ (Vita)	Slow cooling (furnace 30% open until 500°C)	Fast cooling (Below Tg)	Veneering	Modified four-point bending	6.5	10
Passos et al (2017)	Vita VM9 (Vita) Lava Plus (3M ESPE)	Slow cooling (furnace closed until 500°C)	Fast cooling (Below Tg)	Veneering	Four-point bending	0.5	20
Tang et al (2017)	IPS e.max Ceram (Ivoclar) NaturZ (D-Max)	Slow cooling (furnace closed until 500°C)	Fast cooling (Above Tg)	Veneering	Load-to-failure (single crowns)	1.0 or 2.0	10
Meirelles et al (2016)	Vita VM9 (Vita) Ceramco PZF (Dentsply) Vita In Ceram YZ (Vita)	Slow cooling (furnace closed until 50°C below Tg/ 460°C or 510 °C)	Fast cooling (Below Tg)	Veneering	Three-point-bending	1.0	30
Longhini et al (2016)	Vita VM9 (Vita) Vita PM9 (Vita) Vita In Ceram YZ (Vita)	Slow cooling (furnace closed until room temperature)	Fast cooling (Above Tg)	Self-glaze	Piston-on-three-balls	1.0	15
Vichi et al (2015)	Initial Zr-Fs (GC Europe) Adva Zr (GC Europe)	3 or 5 firing cycles	1 firing cycle	Veneering	Three-point-bending	1.2	15
Paula et al (2015)	IPS e.max Ceram (Ivoclar) E.max ZirCAD (Ivoclar)	Slow cooling (furnace closed until 50°C)	Fast cooling (Above Tg)	Over-glaze	Fatigue test (single crowns)	1.5	10
Schmitter et al (2015)	Cercom Ceram press (DeguDent) Cercom base (DeguDent)	Glaze	No glaze	Over-glaze	Three-point-bending Load-to-failure	4.0	8
Almeida Jr. et al (2013)	Vita VM9 (Vita) ZRHP (ProtMat)	Slow cooling (furnace closed until room temperature)	Fast cooling (Above and Below Tg)	Veneering	Three-point-bending	0.5	30
Preis et al (2013)	Lava Ceram (3M ESPE) Lava (3M ESPE)	Slow cooling (6 min of cooling before open the furnace)	Fast cooling (Above Tg)	Veneering	Load-to-failure (single crowns)	2.0	6
Lima et al (2013)	Vita VM9 (Vita) Vita PM9 (Vita) Vita In Ceram YZ (Vita)	Slow cooling (furnace closed until 600°C)	Fast cooling (Above Tg)	Self-glaze	Four-point-bending	1.0 or 3.0	8
Belli et al (2013)	Vita VM9 (Vita) Lava Ceram (3M ESPE) YZ Cubes (Vita)	Slow cooling (furnace 10% opened until 200°C)	Fast cooling (Above Tg)	Self-glaze	Load-to-failure (single crowns)	1.4	16
Lu et al (2012)	Vita VM9 (Vita) Kavo Zirconia (Kavo)	4,6,or 8 firing cycles	2 firing cycles	Veneering	Three-point-bending	0.6	8
Tan et al (2012)	Vita VM9 (Vita) Lava (3M ESPE)	Slow cooling (furnace opened 30% until 500°C)	Fast (Above Tg)	Self-glaze	Modified four-point-bending	6.5	6
Rues et al (2010)	Cercon Ceram Kiss (DeguDent) Cercon Ceram Love (DeguDent) Cercon Base (DeguDent)	Slow cooling (6 min of cooling before open the furnace)	Fast cooling (Above Tg)	Self-glaze	Load-to-failure (single crowns)	2.0	8

Author (year)	Materials	Intervention	Comparison	Last firing	Testing set up	Veneer thickness* (mm)	Sample size (n)
Taskonak et al (2008)	Lava Ceram (3M ESPE) Lava (3M ESPE)	Slow cooling (low cooling rate until room temperature)	Fast cooling (Above Tg)	Heat treatment	Ring-on-ring	0.6	16

*Occlusal thickness when specimens were crowns

Table 2.

Characteristics of the porcelain materials used in the included studies.

Material/ Manufacturer	Composition	Processing method	Elastic module	Coefficient of thermal expansion (CTE)	Glass transition temperature (Tg)	Cooling protocol suggested by the manufacturer
Vita VM9 (Vita)	Feldspathic ceramic	Hand-layered	64.6 GPa[a]	9.0 – 9.2 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	600°C[*]	Furnace closed until 800°C and 25% open until 600°C
Vita PM9 (Vita)	Feldspathic ceramic	Heat-pressed	70 GPa[b]	9.0 – 9.2 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	640°C[b]	Remove the investment ring from the furnace after the end of pressing and place it on a grid to cool it down to room temperature
IPS e.max Ceram (Ivoclar)	Fluorapatite ceramic	Hand-layered	90 GPa[a]	9.5 $10^{-6}K^{-1}$ (100 – 400°C)[*]	490°C[*]	Glaze firing: furnace open after cooling down from 730°C to 450°C. No long-term cooling is indicated for sintering firings.
Ceramco PZF (Dentsply)	Feldspathic ceramic	Hand-layered	75 GPa[c]	9.4 $10^{-6}K^{-1}$[d]	560°C[c]	6 min cooling after maximum temperature (870°C) for glaze firings. No long-term cooling is indicated for sintering firings
Lava Ceram (3M ESPE)	Feldspathic ceramic	Hand-layered	80 GPa[*]	10 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	565°C[d]	No long-term cooling is indicated
Cercon Ceram Kiss (DeguDent)	Feldspathic ceramic	Hand-layered	75 GPa[a]	9.2 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	-	6 min cooling after maximum temperature (800°C) for glaze firings. No long-term cooling is indicated for sintering firings
Cercon Ceram Love (DeguDent)	Feldspathic ceramic	Hand-layered	-	9.2 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	-	6 min cooling after maximum temperature (800°C) for glaze firings. No long-term cooling is indicated for sintering firings
Cercon Ceram press (DeguDent)	Feldspathic ceramic	Heat-pressed	-	10.5 $10^{-6}K^{-1}$ (25 – 500 °C)[*]	-	No long-term cooling is indicated
Initial Zr-Fs (GC Europe)	Feldspathic ceramic	Hand-layered	-	9.4 $10^{-6}K^{-1}$[*]	550°C[*]	No long-term cooling is indicated

[*] Manufacturer,

[a] Sawada et al, 2018,[56]

[b] Choi et al, 2011,[57]

[c] Meirelles et al, 2016,[22]

[d] Taskonak et al, 2008[27]

Table 3.

Risk of bias of included studies.

Author (year)	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14
Ebadian et al (2018)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No
Passos et al (2017)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Tang et al (2017)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Meirelles et al (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No
Longhini et al (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No
Vichi et al (2015)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No
Paula et al (2015)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Schmitter et al (2015)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Almeida Jr. et al (2013)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No
Preis et al (2013)	Yes	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Lima et al (2013)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Belli et al (2013)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Lu et al (2012)	Yes	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	No	No
Tan et al (2012)	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	Yes	No
Rues et al (2010)	Yes	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Taskonak et al (2008)	Yes	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No

1) Structured summary of trial design, methods, results and conclusions, 2a) Scientific background and explanation of rationale, 2b) Specific objectives and/or hypothesis, 3) The intervention of each group, including how and when it was administered, with sufficient detail to enable replication, 4) Completely defined, pre-specified primary and secondary measured of outcome, including how and when they were assessed, 5) How the sample size was determined, 6) Method used to generate the random allocation sequence, 7) Mechanism used to implement the random allocation sequence, 8) who generated the random allocation, 9) Who was blinded after assignment to intervention, 10) Statistical methods used to compare groups, 11) Results for each group and estimated size of effect and its precision, 12) Trial limitations, addressing sources of potential bias, imprecision, and, if relevant multiplicity of analysis, 13) Sources of funding and other support, 14) Where to full trial protocol can be accessed.[31]