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REVIEW ARTICLE

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The effect of grinding and/or airborne-particle abrasion on the bond strength between zirconia and veneering porcelain: a systematic review

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ABSTRACT

Objective: The aim of the study was to make an inventory of current literature on the bond strength between zirconia and veneering porcelain after surface treatment of zirconia by grinding with diamond bur and/or with airborne-particle abrasion.

Material and methods: The literature search for the present review was made following recommended guidelines using acknowledged methodology on how to do a systematic review. The electronic databases PubMed, Cochrane Library, and Science Direct were used in the present study.

Results: Twelve studies were selected. Test methods used in the original studies included shear bond strength (SBS) test, tensile bond strength test, and micro-tensile bond strength test. The majority of studies used SBS. Results showed a large variation within each surface treatment of zirconia, using different grain size, blasting time, and pressure.

Conclusions: Airborne-particle abrasion might improve the bond strength and can therefore be considered a feasible surface treatment for zirconia that is to be bonded. Grinding has been recommended as a surface treatment for zirconia to improve the bond strength; however, this recommendation cannot be verified. A standardized test method and surface treatment are required to be able to compare the results from different studies and draw further conclusions.

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Introduction

The need for high-quality esthetic restoration has resulted in the development of all-ceramic materials as an alternative to the conventional metal-ceramic [1,2]. Zirconia has become the most commonly used all-ceramic core material due to its superior biocompatibility, esthetics, and mechanical properties [2–4]. Due to allergy or the desire for metal-free restorations, increasing numbers of patients object to the use of porcelain-fused-to-metal (PFM) [5]. The development of computer-aided design and manufacturing (CAD/CAM) technology has also contributed to the increasing use of zirconia in dentistry [4], as it contributes to reduced labor, cost effectiveness, and provides a standardized quality [6].

Zirconia is a polymorphic material with three allotropes which are stable in different ranges of temperature (monoclinic at 1170 °C, tetragonal at 2370 °C, and cubic at 2680 °C). In the transition between the tetragonal and the monoclinic phase (T→M), a volume expansion of 3–5% occurs; however, this volume expansion can be used as an advantage by maintaining the tetragonal phase in room temperature. This is achieved by adding an oxide, such as yttria, ceria, or magnesia. The most commonly used oxide is yttria (Y_2O_3), which makes zirconia yttria-stabilized tetragonal zirconia polycrystals (Y-TZP). As a consequence, when Y-TZP is exposed to stress, micro-cracks are formed and, as a result, a phase transformation will occur leading to a volume expansion that will create compressive stresses at the tip of the crack and prevent the crack from propagating. This is called transformation toughening, resulting in a higher fracture toughness of Y-TZP compared to conventional ceramics and alumina-based oxide ceramics, allowing Y-TZP to be used as a framework material for fixed dental prostheses (FDPs) [2,7–9].

To attain better mechanical properties, the replacement of yttria with ceria (Ce) has resulted in a significant increase in fracture toughness, which makes ceria-stabilized tetragonal zirconia polycrystals (Ce-TZP). However, the flexural strength is negatively affected.

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To overcome this low flexural strength, the Ce-TZP is alloyed with alumina (Ce-TZP/A). This makes Ce-TZP/A compatible as a material for FDPs [10,11].

To achieve the appearance of natural teeth, the Y-TZP core is veneered with porcelain. The most frequent reason for failure of all-ceramic restorations is described as 'chip-off fractures' of the veneering porcelain or, more properly, called 'veneering material fractures' [12]. Nevertheless, the survival rate for zirconia-based restorations remains high, despite the veneering material fractures [13]. In a recent review, by Larsson et al. [14], zirconia-based crowns showed a 5-year survival rate exceeding 95%, essentially equal to that of metal-based crowns. However, Larsson et al. [14] also report that, while the survival rates for metal-based and zirconia-based crowns appear to be similar, the reported increased risk of veneering material fractures remains a cause of concern, meaning that, even if the risk of fractures is low, it is still a problem that needs to be addressed [12].

As there are many factors influencing the risk of fracture of the veneering porcelain, the cause of veneering material fractures is complex. The factors that have been discussed are the mechanical properties of the core and veneering material, design, thermal conductivity, and differences in the thickness ratio and the difference in the coefficient of thermal expansion between the core and the veneering material [15]. As the mechanical properties of the veneering porcelain used for zirconia have been improved, they are now comparable with the porcelain used for metal-ceramic restorations. Despite this, the veneering fractures remain a problem [12,16]. Compared to metal frameworks that have mechanical and chemical bonding mechanisms between the metal core and veneering porcelain, knowledge of the bonding mechanisms between Y-TZP and the veneering porcelain is lacking [17]. Many efforts have been made to improve the core and veneer bond strength by modifying the surface properties using various surface treatments, both chemically and mechanically [18,19]. Airborne-particle abrasion with aluminum oxide (Al_2O_3) is one of the most common surface treatments [20]. The application of liner or silica coating is another technique that is often used [7].

Many manufacturers recommend airborne-particle abrasion to increase the surface roughness and ultimately provide undercuts [21]. These undercuts help to increase the surface area, thereby providing better wettability and finally creating micromechanical interlocking. Hence, when using surface treatments, whether it is roughening by airborne-particle abrasion or grinding of zirconia, unavoidable surface damage will occur. This damage creates surface flaws that can induce micro-cracks, which dramatically reduce strength and, consequently, expose the material to fracture [15].

Furthermore, the effects of airborne-particle abrasion are controversial, as some authors claim that airborne-particle abrasion may trigger the phase transformation (T→ M) [19,22]. Phase transformation on the surface of Y-TZP will create stresses in the veneering porcelain due to the differing coefficients of thermal expansion (TEC). The monoclinic phase has a TEC of $7.5 \times 10–6/°C$, and the tetragonal phase has a TEC of $10.8 \times 10–6/°C$. That difference will affect the bond strength between the Y-TZP core and the veneering porcelain. It is crucial that the TEC of the two materials be as close as possible. If the difference in thermal expansion is too big between Y-TZP and the veneering porcelain, it can lead to a decrease in bond strength [22,23]. Some authors suggest that heat treatment after airborne-particle abrasion will reverse the T→ M transformation and reverse any damage created at the surface by releasing the compressive stresses [22,24]. According to one study [25], heat treatment at 1200 °C for 2 h did not show any healing of micro-cracks; however, the stresses were released making it less susceptive to thermal aging.

The purpose of roughening zirconia is to improve the bond strength between core and veneer by micro-mechanical interlocking [15,18]. Surface treatments that have been suggested to improve the core and veneer bond strength include airborne-particle abrasion with alumina oxide or grinding with diamond/sandpaper/disk/wheel [18]. The handling conditions during the process of making a zirconia core differ from technician to technician; therefore, there is no decisive evidence and consensus regarding what effect these surface treatments have on the bond strength of core and veneer.

The aim of this study was to make an inventory of the current literature on the bond strength between zirconia and veneering porcelain after zirconia has been surface treated by grinding with a diamond bur and/or with airborne-particle abrasion (Al_2O_3).

Material and methods

The following question was addressed in the current literature search:

Does grinding and/or airborne-particle abrasion affect the bond strength between the zirconia core and the veneering porcelain?

Definitions

- Oxide ceramics were defined as yttria-stabilized tetragonal zirconia polycrystals (Y-TZP), ceria-stabilized zirconia/alumina (Ce-TZP/A), and magnesia-stabilized zirconia (MSZ).
- Airborne-particle abrasion was defined as particle abrasion with aluminum oxide.
- Grinding was defined as a surface roughening method using a diamond bur/wheel/disk.
- Veneering porcelain was defined as feldspathic porcelain or other synthetic veneering porcelains.
- Bond strength was defined as shear bond strength (SBS), tensile bond strength (TBS), and micro-tensile bond strength (MTBS) since there is no ISO standard for how to test the bond strength between zirconia and veneering porcelain.
- Control group was defined as what the authors stated.

Inclusion and exclusion criteria

Inclusion criteria for the addressed question were: original articles, studies evaluating bond strength between zirconia core and veneering porcelain, zirconia core ground (grinded) and/or airborne-particle-abraded, and studies that included a control group. Pre-treatments, preparation, and cleaning of the specimens were not taken into account.

Exclusion criteria for the addressed question were: review articles, glass ceramics, studies that evaluated different cement systems, and grinding with silicon carbide abrasive papers or carborundum point.

Search strategy

The literature search for the present review was made following recommended guidelines from *Swedish Agency for Health Technology Assessment and Assessment of Social Services* (SBU) and Goodman and by using acknowledged methodology on how to do a systematic review [26,27]. The current literature search was made using the following electronic databases: PubMed (U.S. National Library of Medicine), Science Direct (Elsevier), and Cochrane Library (The Cochrane Collaboration). The search was conducted in January 2016. Four blocks of search terms were created, combining free-text terms by using the Boolean operator 'OR', Block 1 included the free-text terms: 'Y-TZP', 'zirconium', 'zirconia', and 'zirconium dioxide'. Block 2 included the free-text terms: 'dental veneer', 'ceramics', and 'dental porcelain'. Block 3 included the free-text terms: 'grinding', 'airborne-particle abrasion', 'surface treatment', 'sandblasting', and 'blasting'. Block 4 included the free-text terms: 'bond strength' and 'surface properties'. The four blocks were then combined with the Boolean operator 'AND'. No publication date was set, and English was chosen as language filter. The search terms were chosen to be included in title/abstract.

(Y-TZP OR zirconium OR zirconia OR zirconium dioxide) AND (dental veneer OR ceramics OR dental porcelain) AND (grinding OR airborne-particle abrasion OR surface treatment OR sandblasting OR blasting) AND (bond strength OR surface properties)

To complete the literature search, snowballing was conducted, meaning that the reference lists of the retrieved articles were hand searched. Two independent observers read the titles and the abstract separately. The relevant publications were selected through the titles and, when at least one author found one study interesting, it was read in abstract, with the focus on the bond strength between the zirconia core and porcelain veneering. When at least one author found an article relevant, it was read in full-text. Abstracts that differed were discussed and, through common agreement, they were further selected to full-text or excluded. Articles that did not have an abstract available went directly to full-text, and those that were not available in full-text were ordered. Furthermore, the full-text was read independently and disagreements were also resolved through discussion. In the case of articles where the information was unclear, the corresponding authors were contacted. Depending on the information that was given, the article was reevaluated.

Results

Search results

The results of this literature search are presented in a flow diagram, which shows the number of retrieved articles and the following steps of the screening process (Figure 1). In total, 342 publications were identified in the PubMed search. As a result of that, 182 articles were considered relevant after reading the titles. Thereafter, the abstracts were retrieved for further evaluation. Having read the abstracts, 32 potential articles were read in full-text. Following the inclusion and exclusion criteria, a total of 10 relevant articles remained. Additionally, snowballing was performed and a further eight articles were retrieved from the reference lists; however, only one of those eight article remained. Furthermore, one article was found prior to the main search. In the Science Direct

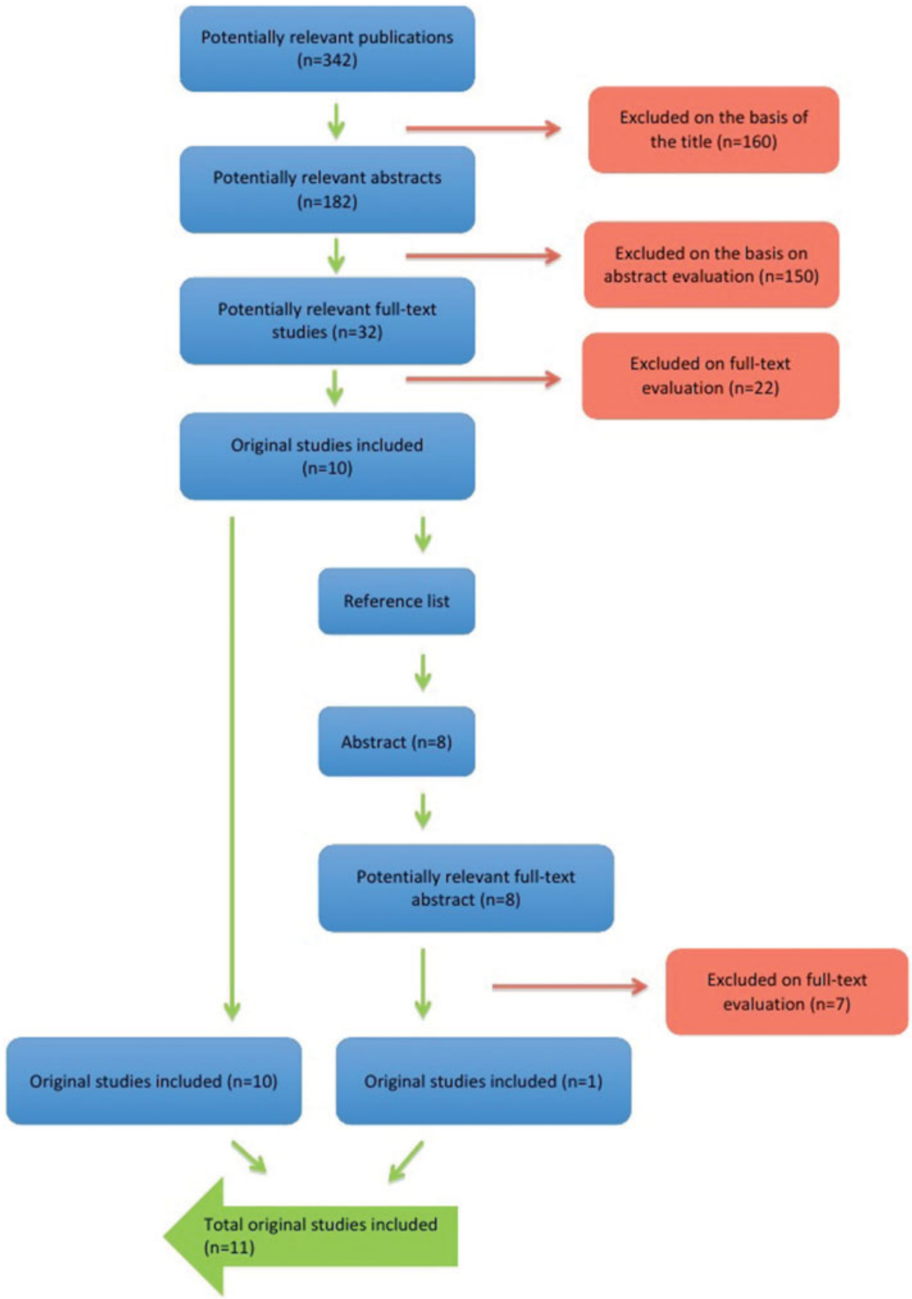

Figure 1. Search strategy and the result of the literature search.

search, 266 publications were identified. In addition, 29 articles were further read in abstract. Finally, six potential articles went on to full-text reading. However, these were already identified in the PubMed search. The search in the Cochrane Library, however, did not produce any publications that were not identified in the PubMed search. In total, 12 articles were included in the present review.

The main reasons for exclusion in full-text were:

- Studies did not match the inclusion/exclusion criteria.
- Studies did not evaluate the bond strength according to the definitions.
- Difficulties determining the final result and the information from corresponding authors was unclear or no answer was given.
- Not original articles.
- Studies did not contain a control group.

Oxide ceramics and veneering porcelain

Among the oxide ceramics that were evaluated in the present study were eight different brands of Y-TZP and one Ce-TZP/A [11]. The majority used Cercon [18,22,28–30] or Lava [7,8,28,31] as a core material. Regarding veneering porcelain, six different brands were identified and the most common were Cerabien ZR [3,11,18,21,31] and Cercon Ceram Kiss [1,22,29–31]. All materials used in the included studies are summarized in Table 1.

Surface treatments

All included studies evaluated airborne-particle abrasion with aluminum oxide particles. The procedure of airborne-particle abrasion varied in pressure, distance, blasting time, and grain size. The majority of the studies used a pressure of 0.2 MPa [11,18,21,31], 0.35 MPa [19,22,28,29], and 0.4 MPa [3,17,18,31]. A distance of 10 mm [3,11,17–19,21,22,30,31] and blasting time of 10 s [3,11,17–19,21,30,31] were used by the majority of the studies. However, one study used a distance of 15 mm and 5 s as blasting time [29], and another study used 15 s as blasting time [22]. The grain size differed more among the studies, ranging from 50 µm to 120 µm (Figure 2). Heat treatment after airborne-particle abrasion was performed in three studies [21,22,31]. Additionally, one study distinguished itself from the other selected studies as the only one that performed airborne-particle abrasion before sintering [18].

Among the included studies, two studies used grinding as a surface roughening method using a diamond bur [19,29] with different grit sizes ranging from 90 µm to 100 µm. All grinding was performed under water cooling and the speed ranged from 20 000 to 200 000 rpm.

Artificial aging

Four studies used artificial aging before carrying out their test method [1,17,22,29]. The artificial aging procedures differed. Two of them used thermocycling, and the number of cycles was set at 20 000 at water temperatures of 5 and 55 °C [1,29]. Water storage (37 °C) was performed in one study for 4 weeks [22]. In one study, cyclic loading was performed with 10 000 cycles with a frequency of 1.5 Hz under room conditions [17].

Control group

The control groups consisted of milled [28,29], non-treated [31], ground [3,19], polished [11,21], or silicon paper abraded [17,18,22] zirconia core. In two studies, the control group consisted of metal-ceramic [1,30].

Test methods

SBS test was evaluated in 10 studies and was the most common test method [1,3,11,17–19,21,22,29,30]. MTBS test was performed in one study [28], and another study used TBS test [31] (Table 1).

Data extraction

The results and conclusions in the included studies are summarized in Table 2. The results of all included studies were gathered to calculate the cumulative mean bond strength values in relation to which test method that was used. The cumulative mean values of SBS for control, airborne-particle abrasion, and grinding were 26.8 MPa, 25.8 MPa, and 22.6 MPa, respectively [1,3,11,17–19,21,22,29,30]. The cumulative mean values of MTBS for control and airborne-particle abrasion were 30.8 MPa and 31 MPa, respectively [28]. The cumulative mean values of TBS for control and airborne-particle abrasion were 22 MPa and 40 MPa, respectively [31].

Discussion

The purpose of a systematic literature review is to systematically collect and summarize available data and to document the results and conclusions in a transparent way that is reproducible. A systematic review should be based on a well-defined question, a set of inclusion and exclusion criteria, and clear evaluation processes. The literature search for the present review was made following recommended guidelines from SBU and Goodman and using acknowledged methodology on how to do a systematic review with some modifications such as not using PICO (population, intervention, control, and outcome) due to the aim of present study [26,27].

Three global databases were used in the search – PubMed, Science Direct, and Cochrane Library – to obtain as much information as possible and to avoid publication bias. Building a search with MeSH terms combined with free-text terms provides a controlled overview of the search, compared to a search done only with free-text terms, because it will give a more sprawled result. However, the pilot search of the present review showed no difference when MeSH terms combined with free-text terms were used, compared to just free-text terms, since the number of found publications was the same. Two studies were not found among the original studies. One because block 3 was not found in title/abstract and PubMed had not indexed the other one at the time. Furthermore, the

Table 1. The results in detail for the included studies.

Studies	Core material	Veneer material	Surface treatments	Artificial aging	Test method	Result mean MPa
Aboushelib et al. [28]	– Cercon (White) – Cercon (Yellow) – Lava (White) – Lava (Yellow) – Procera (Zirconia)	Nobel Rondo, Nobel biocare AB	– Milled surface (C) – Sandblasting Al_2O_3 (SB) – Sandblasting Al_2O_3 coated with liner (SBL)		MTBS	CW (C) 36.5 CW(SB) 42.4 CW (SBL) 28.5 CY (C) 31.6 CY(SB) 24.3 CY(SBL) 29.3 LW (C) 24.8 LW (SB) 29.7 LW(SBL) 23.4 LY (C) 30.1 LY (SB) 20.8 LY(SBL) 29.4 P (C) 30.8 P(SB) 49.8 P(SBL) 31.9
Fischer et al. [21]	Vita In-Ceram YZ Cubes	– Cerabien Zr – Vintage ZR – VM9 – Triceram	– Polished with diamond paste (C) – Sandblasting Al_2O_3 (SB) – Sandblasting Al_2O_3 coated with liner (SBL) – Heat treatment after sandblasting Al_2O_3 for group VM9 (SBHT)		SBS	CZ (C) ≈ 28 CZ (SB) ≈ 27.5 CZ(SBL) ≈ 27 VZ (C) ≈ 23.5 VZ (SB) ≈ 29.5 VZ (SBL) ≈ 22.5 VM9 (C) ≈ 30.5 VM9 (SB) ≈ 29.5 VM9 (SBL) ≈ 29 VM9 (SBHT) ≈ 19 T (C) ≈ 31 T (SB) ≈ 21 T (SBL) ≈ 26
Guess et al. [1]	Cercon	Cercon Ceram S	– Metal-ceramic (C) – Sandblasting Al_2O_3 coated with liner (SBL)	Half group Thermocycling 20,000 cycles (5–55 °C)	SBS	(C) 27.6 (C)[a] 26.4 (SBL) 9.4 (SBL)[a] 9.6
He et al. [18]	Nissin-Metec	Cerabien ZR	– Polished with silicone paper (C) – Sandblasting Al_2O_3(SB) – Sandblasting Al_2O_3 before sintering (SBBS)		SBS	(C) 20.97 (SBBS)** 35.02 (SB)** 25.04 (SB)*** 29.82
Kim et al. [3]	Kavo Everest ZS	Cerabien ZR	– Ground with diamond disk #320 (G) – Sandblasting Al_2O_3 (SB) – Sandblasting Al_2O_3 coated with liner (SBL)		SBS	(G) 32.08 (SB) 36.63 (SBL) 30.51
Korkmaz et al. [19]	Zirkonzahn	VM9	– Grinding with diamond bur 100 µm (G) – Sandblasting Al_2O_3 (SB)		SBS	(G) 11.59 (SB) 11.64
Liu et al. [22]	Cercon	Cercon Ceram Kiss	– Silicon paper (C) – Sandblasting Al_2O_3 coated with liner (SBL) – Heat treatment after sandblasting Al_2O_3 coated with liner (SBTHL)	Half of the specimens were stored in 37 °C water for 4 weeks (WS)	SBS	(C) 24.8 (SBL) 31.3 (SBHTL) 29.2 (CWS) 25.6 (SBLWS) 28.3 (SBHTLWS) 27.9
Mosharraf et al. [29]	– Cercon (White). – Cercon (Colored)	Cercon Ceram Kiss	– Milled (C) – Sandblasting Al_2O_3 (SB) – Grinding with diamond bur 90 µm (G) – Sandblasting Al_2O_3 coated with liner (SBL)	All specimens were thermocycled 20.000 cycles (5–55 °C)	SBS	W (C) 30.83 W (G) 21.33 W (SB) 26.31 W(SBL) 27.39 C (C) 25.73 C (G) 25.39 C (SB) 28.51 C (SBL) 29.50
Nakamura et al. [31]	Lava	– Vintage ZR (VZ) – Cercon Ceram Kiss (CCK) – Cerabien ZR (CZ)	– Non treated (C) – All specimens were heat treatment		TBS	(C) 22 VZ* 27.8 VZ** 44.3 VZ*** 40.2

(*continued*)

Table 1. Continued

Studies	Core material	Veneer material	Surface treatments	Artificial aging	Test method	Result mean MPa
			after sandblasting Al_2O_3 with different pressure and coated with liner			CCK** 49.5 CZ** 37.8
Nishigori et al. [17]	Diazir	Vintage ZR	– Ground with silicon carbide paper (C) – Sandblasting Al_2O_3 (SB) – Heat treatment after sandblasting Al_2O_3 (SBHT)	Half the group were cyclic loaded (CL)	SBS	(C) 21.3 (CCL) 23.8 (SB) 34.1 (SBCL) 10.7 (SBHT) 17.5 (SBHTCL) 29.3
Oguri et al. [11]	P-NANO ZR	Cerabien	– Polished with whetstone #325, #1000 (C) – Sandblasting Al_2O_3 (SB)		SBS	(C) 15.35 (SB) 20.46
Teng et al. [30]	Cercon base	Cercon Ceram S	– Metal-ceramic (C) – Sandblasting Al_2O_3 (SB)		SBS	(C) 46.12 (SB) 39.14

[a]Thermocycling.
*0.2 MPa blasting pressure.
**0.4 MPa blasting pressure.
***0.6 MPa blasting pressure.

Table 2. A summary of the authors own results.

Included studies were the author is presented in alphabetical order	Summary of the results
Aboushelib et al. [28]	The bond strength of the airborne-particle abraded Cercon white and Lava white had higher bond strength than the milled group (control group), but not significant. Cercon yellow and Lava yellow had significant lower bond strength than the milled group. Moreover, comparing the white and yellow of the same manufacture, the yellow had significant lower micro-tensile bond strength than the white group.
Fischer et al. [21]	Airborne-particle abrasion did not increase the shear bond strength significantly. A significant decrease in shear bond strength for Vintage ZR after airborne-particle abrasion in conjunction with liner and polished with liner. A significant difference was found between polished and airborne-particle abraded within the group of Triceram.
Guess et al. [1]	Thermocycling did not have any effect on the shear bond strength in any test group. Airborne-particle abrasion did not have a significant influence on the bond strength between core and veneer.
He et al. [18]	Airborne-particle abrasion before sintering had a significantly higher shear bond strength than the control group and the airborne-particle abraded group after sintering. A significant difference was also found in shear bond strength between the airborne-particle abraded group after sintering and control group.
Kim et al. [3]	No significant difference was found between the groups.
Korkmaz et al. [19]	No significant difference between the airborne-particle abraded group and the ground group with diamond bur, however, airborne-particle abraded had higher bond strength.
Liu et al. [22]	The lowest initial mean shear bond strength was obtained in the control group, which was significantly lower than the airborne-particle abraded group. No significant difference between airborne-particle abrasion and airborne-particle abrasion with heat treatment was found. The values of the initial mean shear bond strength was not significantly different from the groups that were stored in water.
Mosharraf et al. [29]	Different types of zirconia ceramics had no significant effect on the shear bond strength. No significant difference was found within the colored zirconia group. However, in the white zirconia group a significant difference was found, in particular, the ground group that showed significantly lower shear bond strength values than as milled (C) and airborne-particle abraded with liner.
Nakamura et al. [31]	Airborne-particle abrasion with 0.4 or 0.6 MPa showed significantly higher bond strength compared to the airborne-particle abraded group of 0.2MPa. There was no significant difference in bond strength among the different veneering porcelains.
Nishigori et al. [17]	The highest mean shear bond strength value was observed for the airborne-particle abraded group without cyclic loading. In contrast to the airborne-particle abraded group with cyclic loading that showed the lowest values. However, no significant effect of surface treatment and cyclic loading on the bond strength was found, except for the group that was airborne-particle abraded, as cyclic loading for this group resulted in a decrease in shear bond strength.
Oguri et al. [11]	Airborne-particle abrasion and grinding showed significantly higher shear bond strength values compared to the control group. The highest value was obtained in the airborne-particle abraded group. However, no significant difference was found between the airborne-particle abraded and grinded group.
Teng et al. [30]	A significant difference among the test groups was observed. Further, airborne-particle abrasion showed lower shear bond strength values than control (metal ceramic).

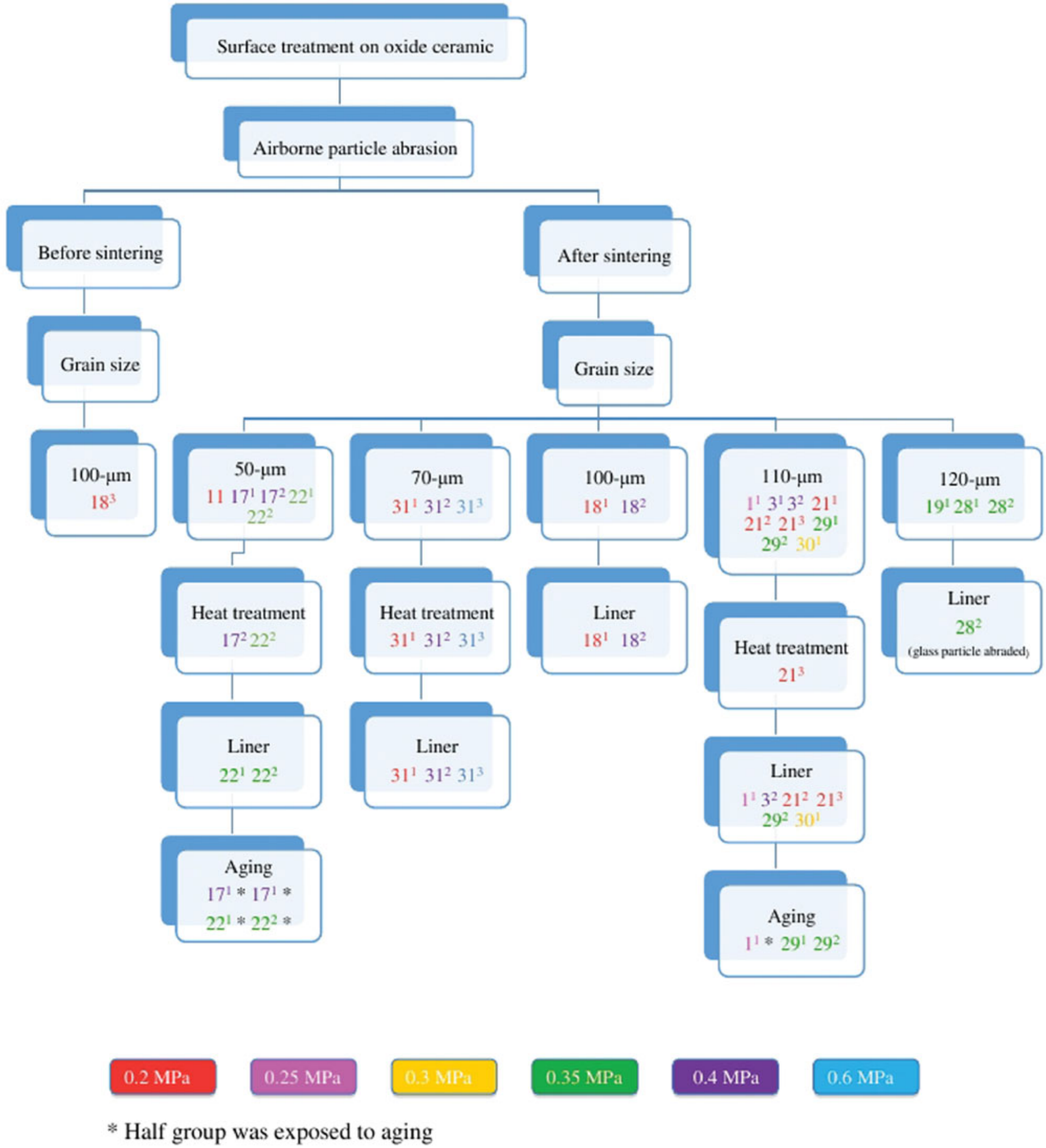

Figure 2. A schematic illustration and an overview of the different surface treatments. Each number refers to a study, and each exponent number represents a surface-treated group.

same search blocks were conducted in all three databases.

A total of 12 studies were included in the present systematic review and the result showed a large variation within each surface treatment for oxide ceramics and differences in the selection of test methods evaluating bond strength of core and veneer. This makes it very difficult to compare the studies with one another.

The purpose of roughening zirconia is to improve the core and veneer bond strength by micromechanical interlocking [15,18]. Surface treatments that have been suggested to improve the core and veneer bond strength include airborne-particle abrasion with

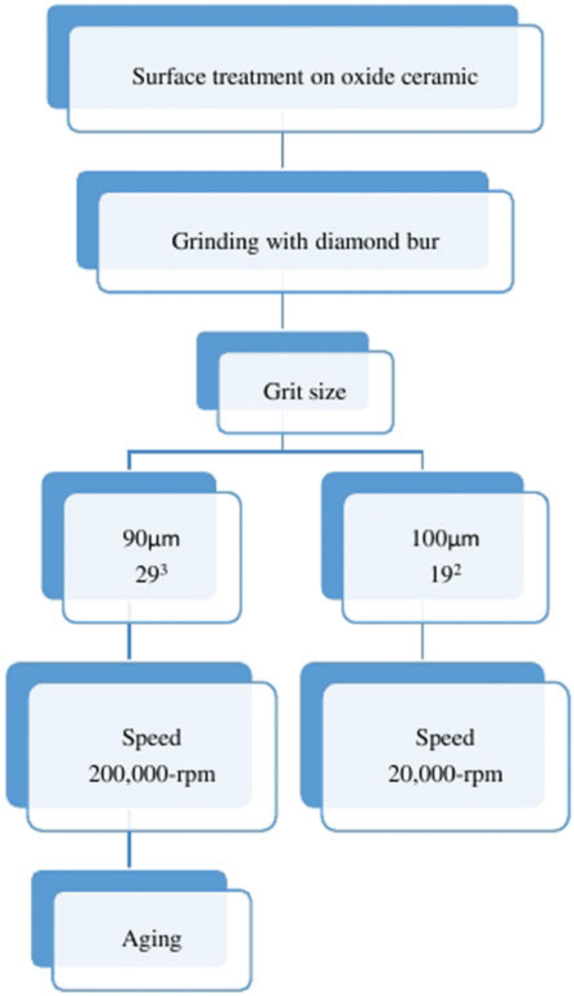

Figure 2. Continued.

alumina oxide or grinding with diamond/sandpaper/disk/wheel [18]. Since, there is no standard in the process of treating zirconia, regardless of surface treatment, one can find numerous variations, as seen in the findings of the present review.

To increase the bond strength between core and veneer, airborne-particle abrasion is a common surface treatment. The bond strength is determined by the weakest component [19] and, according to a few studies [2,8,19,21,30], the weakest component is not the interface, but the veneering porcelain itself. This may explain why the bond strength has not increased when the surfaces have been treated with airborne-particle abrasion. Nevertheless, there are studies [22,31] stating the opposite, that airborne-particle abrasion with 0.4 MPa produces higher bond strength value and, at the same time, the flexural strength of Y-TZP is not significantly affected.

Based on the results from the present study, one could see that airborne-particle abrasion in the majority of the included studies gave a numeric difference compared to the control groups [3,17,21,28–30]. This might indicate that airborne-particle abrasion as a surface treatment is in need of a subdivided surface treatment to further enhance the effects of airborne-particle abrasion. Nakamura et al. [31] stated that airborne-particle abrasion with 0.4 MPa and a grain size of 70 µm will not damage the surface and will develop a strong bond between Y-TZP and veneering porcelain. Similarly to Nakamura et al. [31], Liu et al. [22] found a significant difference after airborne-particle abraded with 0.35 MPa and a grain size of 50 µm when compared to control group, meaning that airborne-particle abrasion resulted in higher bond strength. This might indicate that blasting between 0.35 and 0.4 MPa with a grain size around 50 µm or 70 µm significantly improves the result of bond strength. This might be supported by a study that found that airborne-particle abrasion with 50 µm aluminum oxide is less severe to the surface of Y-TZP compared with 120 µm particles delivered at the same pressure and offset distance [32]. Hence, the result of the present review showed that the majority of the studies that performed airborne-particle abrasion used a pressure of 0.2 MPa and grain size at 110 µm. This might explain why no significant improvement in bond strength was found, although, Oguri et al. [11] found higher SBS when airborne-particle abraded with 50 µm particle size at a pressure of 0.2 MPa. However, this was on ceria-stabilized tetragonal zirconia/alumina.

He et al. [18] found that airborne-particle abrasion with 0.2 MPa before sintering improved the surface roughness by 500%, compared with the groups that were airborne-particle abraded after sintering. Consequently, this indicates that airborne-particle abrasion before sintering could be a useful method to improve surface roughness and successfully improve the bond strength between zirconia and the veneering porcelain. This might be explained, as He et al. [18] describes it, by the much lower hardness of zirconia prior to sintering, resulting in a rougher surface and creating a larger surface area for mechanical interlocking. However, comparing airborne-particle abrasion of 0.4 MPa after sintering with 0.2 MPa before sintering, no significant difference was found. This might indicate that surface roughness and bond strength may not be linear, even though airborne-particle abrasion with 0.2 MPa before sintering showed higher surface roughness [18]. Moreover, Kim et al. [3] claim that surface roughness increases the contact area, which helps to reduce the interfacial failure of the core and veneer, suggesting that it contributes to an increase in bond strength of the core and veneer. However, there are those who claim the opposite, meaning that airborne-particle abrasion will cause a phase transformation (T→M) on the surface. Due to the development of micro-cracks, a greater amount of monoclinic phase will be created at the surface and eventually lead to a decrease in bond strength [2,33]. It is also believed that the amount of monoclinic phase greatly depends on the particle size, blasting pressure, and blasting time [3].

As a result of the present review, one could see that all the included studies, apart from He et al. [18], performed airborne-particle abrasion after sintering, even though previous studies have reported that surface treatments performed *after* sintering increase the fracture risk, weaken the structure by inducing micro-cracks, and increase the content of monolithic phase [24,34,35]. In contrast, surface treatments *before* sintering have been recommended as it helps to increase the fraction of the tetragonal phase, thereby enhancing the mechanical properties of Y-TZP [18,34]. Additionally, further studies are needed for a clearer evaluation on the effects of airborne-particle abrasion before sintering, as these results and conclusions are based on one study found in the present review.

Grinding with diamond is a common step of fabrication to bring out individual structures on the Y-TZP core. Mechanical grinding on the surface can cause a phase transformation, which can generate higher levels of stress and cause a significant decrease in the flexural strength [29,36]. According to Korkmaz et al. [19], grinding did not improve the SBS between core and veneer, in contrast to the assumption that a rougher surface area of Y-TZP provides a better bonding. In agreement, Mosharraf et al. [29] reported that grinding had a negative effect on the SBS, as it showed significantly lower SBS values when compared to the control group and to airborne-particle abrasion with the use of a liner. This might be because grinding does not create undercuts like airborne-particle abrasion and, therefore, it is not able to create micromechanical interlocking between the Y-TZP and the veneering porcelain.

One can assume that the use of artificial aging is a standard procedure when evaluating the bond strength between two materials. However, in the present systematic review, only four studies used artificial aging [1,17,22,29]. Artificial aging is an essential part while making an *in vitro* study, as it may otherwise lead to unrealistically high strength values, ultimately affecting the results and not making it comparable *in vivo* [12,20]. Commonly used methods to simulate aging of a material are thermocycling or cyclic preloading in a wet environment, by resembling the fatigue process in the oral environment [12]. In a complex situation such as the oral environment, the oral fluids are known to promote stress corrosion of ceramic materials, which enhances crack growth when water is present at the crack tip. This may lead to further failure, reduce the fracture strength, and lead as well to the development of flaws in the ceramic material [1,12,37]. In the two studies that used thermocycling as the aging procedure, the number of cycles was set at 20 000 with a temperature range between 5 and 55 °C. The result from one of the studies [1] showed no significant effect on the SBS after thermocycling, while the other one did not evaluate the effect of thermocycling at all [29]. The ISO/TS1140:2003 standard for thermocycling recommends using 500 cycles in a water temperature range between 5 and 55 °C as an appropriate aging method [12,20].

But, since there is no consensus regarding the appropriate procedure for aging, the number of cycles therefore varies [12]. Another identified artificial aging procedure was a short-term water storage that was performed at 37 °C over a 4-week period. According to the study [22], water storage under a short period of time did not have any effect on the bond strength. However, according to the ISO standard 5.1.4.5, long-term storage for 6 months in water with a temperature of 37 °C is appropriate [20]. This might explain why no difference was observed in the study [22], since seeing any effect after such a short amount of time does not seem likely. Additionally, cyclic loading was performed in one study [17], in room conditions. However, no significant difference of cyclic loading was found, except for the airborne-particle-abraded group where cyclic loading resulted in a decrease of SBS. The specimens were stored in water under room conditions, which make it difficult to compare with the clinical situation. Nevertheless, stimulated aging has its limitations and will never be able to replace the real conditions of the oral environment [20]. Artificial aging should be considered as a standard procedure to simulate aging when evaluating the bond strength between different interfaces.

In this present review, four studies [17,21,22,31] evaluated the effect of heat treatment after surface treatment. Heat treatment can reverse transformation and release the compressive stresses [17]. However, according to two of the authors [17,21], heat treatment significantly decreased the bond strength. The decrease in bond strength might be explained by the fact that heat treatment can relax the compressive stresses at the surface but the micro-cracks do not close at the temperature of 1000 °C, meaning that the overall strength of Y-TZP is decreased [21]. By way of contrast, Liu et al. [22] stated that heat treatment neither reduced nor enhanced the effect of airborne-particle abrasion.

Two studies [28,29] investigated whether using different Y-TZP materials had any effect on the bond strength, specifically looking for differences between white and colored material. According to Aboushelib et al. [28], the colored group showed significantly lower MTBS than the white group. This contrasts with Mosharraf et al. [29], where no significant difference between the colored and white group was found, although lower SBS values were obtained from the white group. Aboushelib et al. [28] believes that color pigments in the Y-TZP cause structural changes that affect the core and veneer bond strength. This indicates that colored Y-TZP can have an effect on the bond strength. It should also be mentioned that these two studies used different test methods, consequently making it difficult to compare the results. Therefore, it would be interesting to see more studies on colored zirconia.

Different test methods can be used to evaluate the bond strength between the zirconia core and veneering porcelain, each with advantages and disadvantages [18]. The variation of test methods makes it hard to compare the values. In the present review, one could see that the majority of the selected studies evaluated the bond strength with SBS test [1,3,11,17–19,21,22,29,30]. Furthermore, the advantage of this test is that it is easy to use and the applied forces are vertical to the bonding area [29]; however, the test's reliability is questioned [20], as it can lead to undesirable stress pattern distribution, causing cohesive fractures and inaccurate interpretation of the data [2]. MTBS [28] and TBS [31] are two other test methods that have been used in the included studies. According to Aboushelib et al. [28], the MTBS test has advantages, such as that the applied force is perpendicular to the test interface, and that the microbars reduce the risk of inner structural flaws, therefore giving a more accurate result on the core and veneer bond strength. The drawback of the MTBS test is the need for careful handling of the specimens to avoid structural defects. The advantages of the TBS test are that the stresses are less complex due to the small amount of material consumed when the test is performed. The drawback is that the attachment of the specimens can produce inhomogeneous stresses and affect the result [20]. However, standardization for evaluating bond strength on all-ceramic has not yet been determined [2,3]. Therefore, development of a stricter standardized method to test the bond strength is necessary to obtain clinically valuable data [29].

Two studies were excluded because they did not evaluate the bond strength according to the definitions set for the present review [2,8]. To evaluate the bond strength, a three-point bending test was performed, where Doi et al. [2] used the crack initiation strength test. In the present review, flexural strength tests were excluded because they have been proven to give inaccurate results when evaluating bi-layered all-ceramic restorations [2]. According to Doi et al. [2], the actual bond strength between zirconia and veneering porcelain was not being tested, since cracks initiated and propagated totally within the veneering porcelain.

Finally, the results of all included studies were gathered to calculate the cumulative mean bond strength values relative to which test method was used. The results showed that the lowest cumulative mean SBS was observed for the ground group. Furthermore, the highest cumulative mean SBS was found in the control group; however, one should keep in mind that two studies used metal-ceramic as their control group, consequently providing a higher value for the control group. It is hard to draw any conclusions based upon the results shown by the respective studies, as they use different materials and test methods, ultimately making the results scattered. Moreover, since only one study tested MTBS and only one other study tested TBS, further statements were not able to be made. The few number of studies testing MTBS and TBS might indicate that these test methods are harder to perform.

As observed in the present review, it is hard to draw any conclusions, since there are no standards regarding surface treatments and test methods evaluating the bond strength. The result is therefore scattered. However, one can see in the results of the present review that surface treatments differ depending on a variety of factors, such as the recommendations of the dental technician and the manufacturer. In other words, there is a need for standardized methods in surface treatment and the evaluation of bond strength. Further research is needed based on a well-defined standard in order to be able to compare the studies to one another.

Based on the findings and limitations of the present review, the following conclusions are drawn: airborne-particle abrasion might improve the bond strength and can therefore be considered as a feasible surface treatment for zirconia that is to be bonded. Grinding has been recommended as a surface treatment for zirconia to improve the bond strength; however, this recommendation cannot be verified. A standardized test method and surface treatment are required to be able to compare the results from different studies and draw further conclusions.

Disclosure statement

None to declare.

References

[1] Guess PC, Kulis A, Witkowski S, et al. Shear bond strength between zirconia core and veneering ceramics and their susceptibility to thermocycling. Dent Mater. 2008;24:1556–1567.

[2] Doi M, Yoshida K, Atsuta M, et al. Influence of pretreatments on flexural strength of zirconia and debonding crack-initiation strength of veneered zirconia. J Adhes Dent. 2011;13:79–84.

[3] Kim HJ, Lim HP, Park YJ, Vang MS. Effect of zirconia surface treatments on the shear bond strength of veneering ceramic. J Prosthet Dent. 2011;105:315–322.

[4] Larsson C, EI Madhoun S, Wennerberg A, et al. Fracture strength of yttria-stabilized tetragonal zirconia polycrystals crowns with different design: an in in vitro study. Clin Oral Implants Res. 2012;23:820–826.

[5] Christensen GJ. Porcelain-fused-to-metal versus zirconia-based ceramics restoration. J Am Dent Assoc. 2009;14:1036–1039.

[6] van Noort R. The future of dental devices is digital. Dent Mater. 2012;28:3–12.

[7] Kim ST, Cho HJ, Lee YK, et al. Bond strength of Y-TZP-zirconia ceramics subjected to various surface roughening methods and layering porcelain. Surf Interface Anal. 2010;42:576–580.

[8] Yamaguchi H, Ino S, Hamano N, et al. Examination of bond strength and mechanical properties of Y-TZP zirconia ceramics with different surface modifications. Dent Mater J. 2012;31:472–480.

[9] Al-Ahmed B, Lyons K, Swain M. Clinical trials in zirconia: a systematic review. J Oral Rehabil. 2010;37:641–652.

[10] Fisher J, Stawarczyk B, Sailer I, et al. Shear bond strength between veneering ceramics and ceria-stabilized zirconia/alumina. J Prosthet Dent. 2010;103:267–274.

[11] Oguri T, Tamaki Y, Hotta Y, et al. Effects of a convenient silica-coating treatment on shear bond strengths of porcelain veneers on zirconia-based ceramics. Dent Mater J. 2012;31:788–796.

[12] Johansson C, Kmet G, Rivera J, et al. Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns. Acta Odontol Scand. 2014;72:145–153.

[13] Le M, Papia E, Larsson C. The clinical success of tooth- and implant-supported zirconia-based fixed dental prostheses. A systematic review. J Oral Rehabil. 2015;42:467–480.

[14] Larsson C, Wennerberg A. The clinical success of zirconia-based crowns: a systematic review. Int J Prosthodont. 2014;27:33–43.

[15] Rekow ED, Silva NR, Coelho PG, et al. Performance of dental ceramics: challenges for improvements. J Dent Res. 2011;90:937–952.

[16] Fisher J, Stawarczyk B, Hämmerle CH. Flexural strength of veneering ceramics for zirconia. J Dent. 2008;36:316–321.

[17] Nishigori A, Yoshida T, Bottino MC, et al. Influence of zirconia surface treatment on veneering porcelain shear bond strength after cyclic loading. J Prosthet Dent. 2014;122:1392–1398.

[18] He M, Zhang Z, Zheng D, et al. Effect of sandblasting on surface roughness of zirconia-based ceramics and shear bond strength of veneering porcelain. Dent Mater J. 2014;33:778–785.

[19] Korkmaz FM, Bagis B, Turgut S, et al. Effect of surface treatments on the bond strength of veneering ceramic to zirconia. J Appl Biomater Funct Mater. 2015;13:17–27.
[20] Papia E, Larsson C, du Toit M, et al. Bonding between oxide ceramics and adhesive cement systems: a systematic review. J Biomed Mater Res B Appl Biomater. 2014;102:395–413.
[21] Fisher J, Grohmann P, Stawarczyk B. Effect of zirconia surface treatments on the shear strength of zirconia/veneering ceramic composites. Dent Mater J. 2008;27:448–454.
[22] Liu D, Matinlinna JP, Tsoi JK, et al. A new modified laser pretreatment for porcelain zirconia bonding. Dent Mater. 2013;29:559–565.
[23] Tada K, Sato T, Yoshinari M. Influence of surface treatment on bond strength of veneering ceramics fused to zirconia. Dent Mater J. 2012;31:287–296.
[24] Kirmali O, Akin H, Ozdemir AK. Shear bond strength of veneering ceramic to zirconia core after different surface treatments. Photomed Laser Surg. 2013;31:261–268.
[25] Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24:299–307.
[26] Swedish Agency for Health Technology Assessment and Assessment of Social Services. Vår metod. Stockholm: Swedish Council on Technology Assessment in Health Care Stockholm; 2014.
[27] Goodman C. Literature searching and evidence interpretation for assessing health care practices. Stockholm: Swedish Council on Technology Assessment in Health Care Stockholm; 1993.
[28] Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Effect of zirconia type on its bond strength with different veneer ceramics. J Prosthodont. 2008;17:401–408.
[29] Mosharraf R, Rismanchian M, Savabi O, et al. Influence of surface modification techniques on shear bond strength between different zirconia cores and veneering ceramics. J Adv Prosthodont. 2011;3:221–228.
[30] Teng J, Wang H, Liao Y, et al. Evaluation of a conditioning method to improve core-veneer bond strength of zirconia restorations. J Prosthet Dent. 2012;107:280–387.
[31] Nakamura T, Wakabayashi k, Zaima C, et al. Tensile bond strength between tooth-colored porcelain and sandblasted zirconia framework. J Prosthodont Res. 2009;53:116–119.
[32] Wang H, Aboushelib MN, Feilzer AJ. Strength influencing variables on CAD/CAM zirconia frameworks. Dent Mater. 2008;24:633–638.
[33] Kosmac T, Oblak C, Jevnikar P, et al. The effect of surface grinding and sandblasting on flexural strength and reliability of Y-TZP zirconia ceramic. Dent Mater. 1999;15:426–433.
[34] Kirmali O, Kapdan A, Kustarci A, et al. Veneer ceramic to Y-TZP bonding: comparison of different surface treatments. J Prosthodont. 2015;21:1–6.
[35] Guess PC, Zhang Kim JW, et al. Damage and reliability of Y-TZP after cementation surface treatment. J Dent Res. 2010;89:592–596.
[36] Karakocka S, Yilmaz H. Influence of surface treatments on surface roughness, phase transformation and biaxial flexural strength of Y-TZP ceramics. J Biomed Mater Res B Appl Biomater. 2009; 92:930–937.
[37] Kohorst P, Dittmer MP, Borchers L, et al. Influence of cyclic fatigue in water on the load-bearing capacity of dental bridges made of zirconia. Acta Biomater. 2008;4:1440–1447.